The machine intelligence of images.

MVA 2023

The machine intelligence of images – Course Overview

Course Objectives:

- Dive into the complexity of the design of today's smartphone cameras, which drives most of the technology in the image processing area.
- Understand the gap between the 'academic' image processing algorithms and their integration into a product.
- We will cover:
  - An overview of the smarphone camera industry (hardware and software)
  - The basic and advanced image processing pipelines
  - The hardware implementation constraints
  - The evaluation of the image quality with a visit in DxOMark Labs.

- 8 x 2h of lectures
- 4 x 3h of TPs.
- mini projects, evaluated through an oral presentation.

The machine intelligence of images – Course Overview

Lectures :

- Introduction to cameras and the industrial ecosystem (F. Guichard / W. Hauser)
- DSLR vs Smartphone – the sensitivity and denoising challenge (F. Guichard / W. Hauser)
- Image Quality Analysis from RAW to Final Image quality (C. Greco / B. Pochon)
- Multi-Images / Multi-Sensors (B. Neveu)
- Color Processing, HDR Format (W. Hauser / B. Pochon)
- Image processing/machine learning implementation constraints (M. Karpushin / W. Hauser)
- IA from cameras to IQ evaluation (S. Ferradans / B. Pochon)

Participants :

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DXOMARK

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DXOMARK

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Xiaomi

Introduction to cameras and the industrial ecosystem

The machine intelligence of images.

F. Guichard / W. Hauser

Cameras are everywhere

Ingredients of a digital camera

Lens

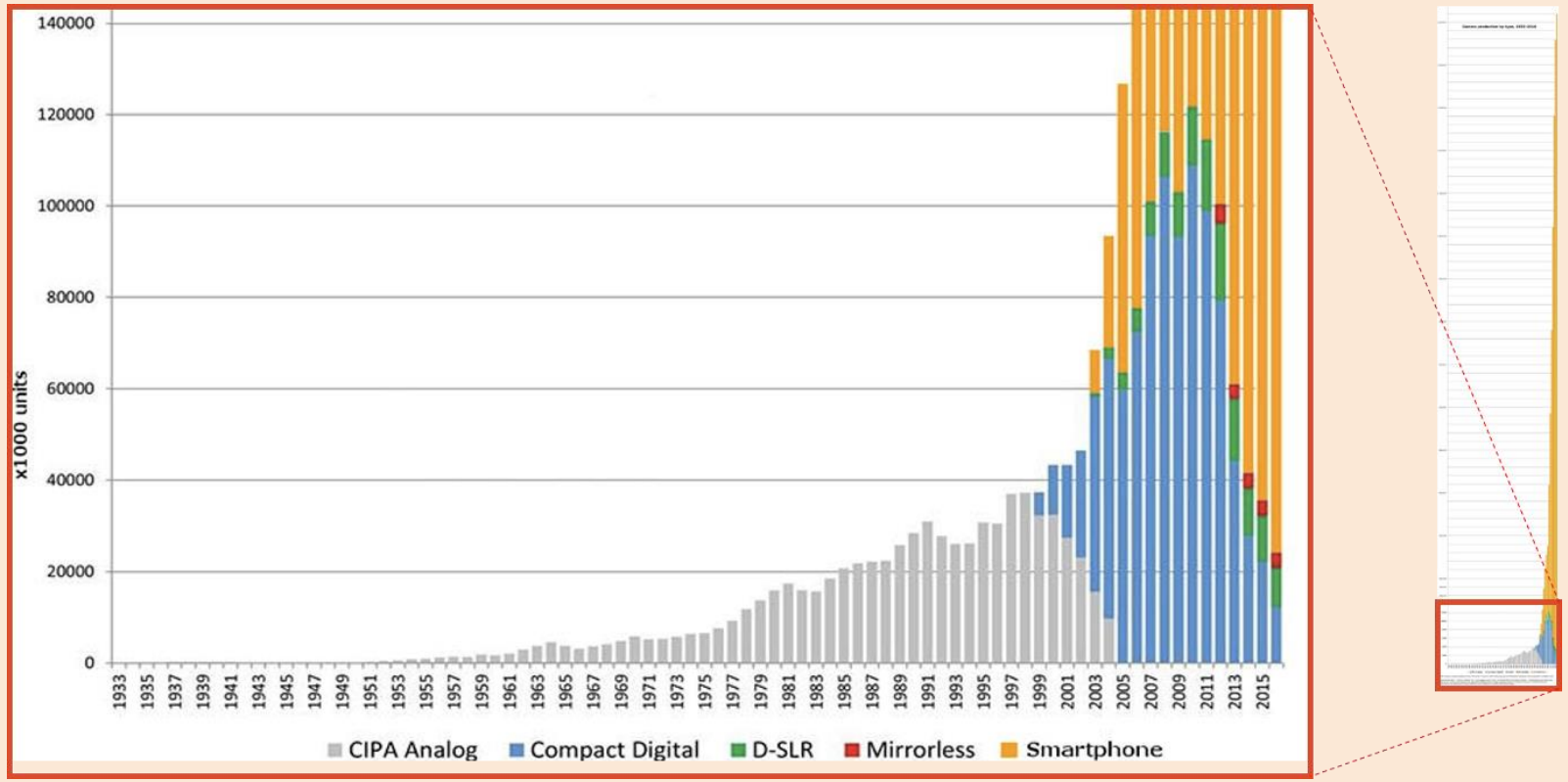
Screen

Image signal processor (ISP)

Sensor

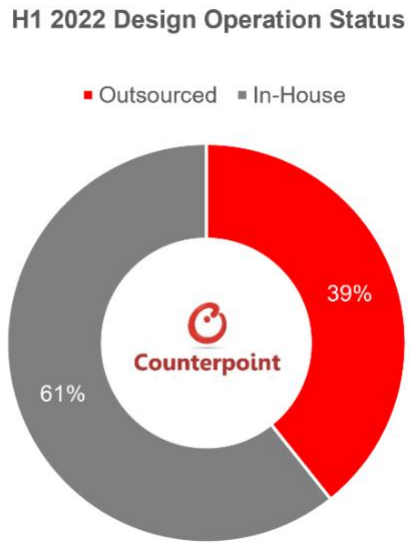
Source: https://www.northlight-images.co.uk/canon-eos-m-and-m2/

Camera Industry Trend



- The smartphones manufacturers
  - Hardware and Software (co-design)
- Post-processing Software

Smartphones Brands / Vendors / ODM / OEM / EMS



- **OBM / Brand** : Apple, Samsung, Huawei, Xiaomi, etc…
  - ODM = Original Design Manufacturer : Design and build a product
  - OEM = Original Equipment Manufacturer : Build a product according to specifications given to them
  - EMS = Electronics manufacturing Services : Just manufacture…
  - IDH = Design house : Just does the design, but does not manufacture

- **OEM or ODM model**
  - Apple = OEM model, with Foxconn as OEM/EMS
  - Samsung = OEM model for S series, ODM for low-end series.
  - Crosscall = ODM model, with Hisense as ODM

- Major smartphones ODM/EMS/IDH
  - *Huaqin, Longcheer, Wingtech, Tinno*
- Major smartphones EMS/OEM
  - Foxconn, *Pegatron, ... Quanta, BYD, Flex, Inventec,*

#1	ODM	Shipment share (H1 2022)
1	Huaqin	30%
2	Longcheer	25%
3	Wingtech	20%
4	Tinno	8%
5	CNCE	6%
	others	11%

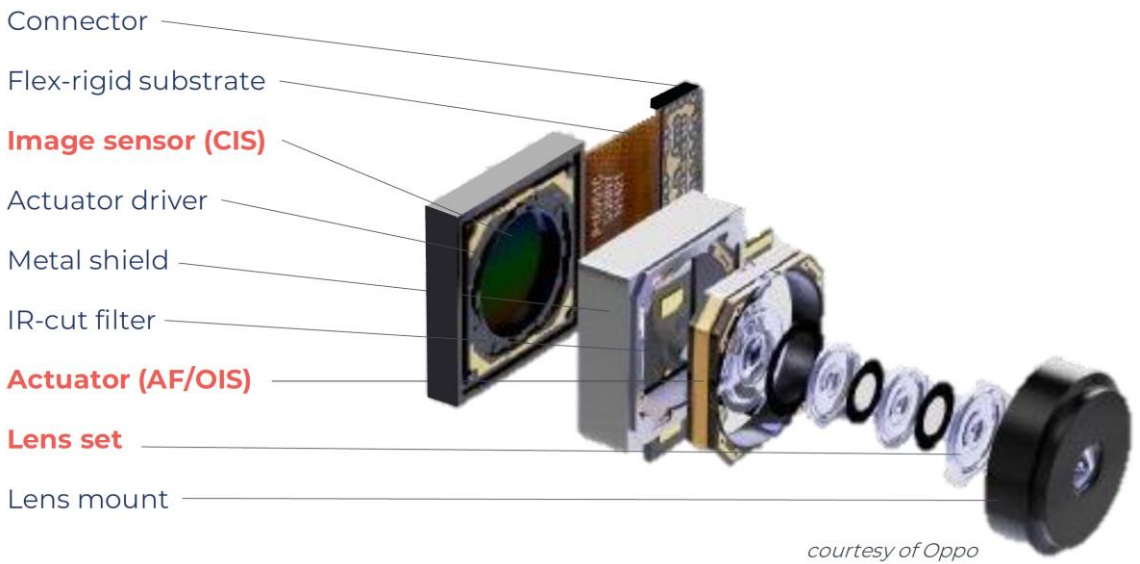
Smartphone’s Camera ingredients

- Camera module(s)
  (and other sensors)
- The image processing

Inside a Camera Module

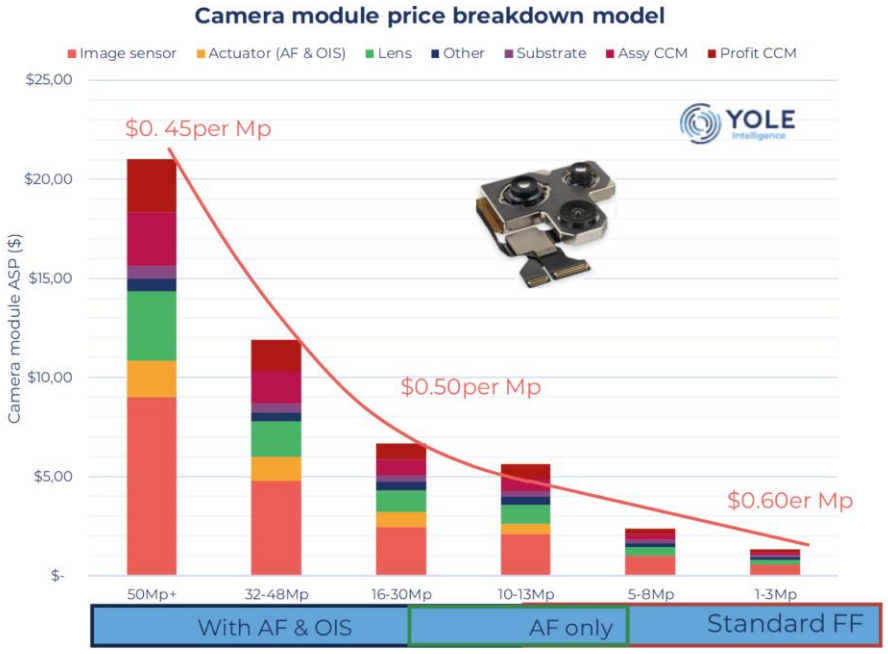
- The lens set made of lenses
- The actuators (AF/OIS)
- The image Sensor

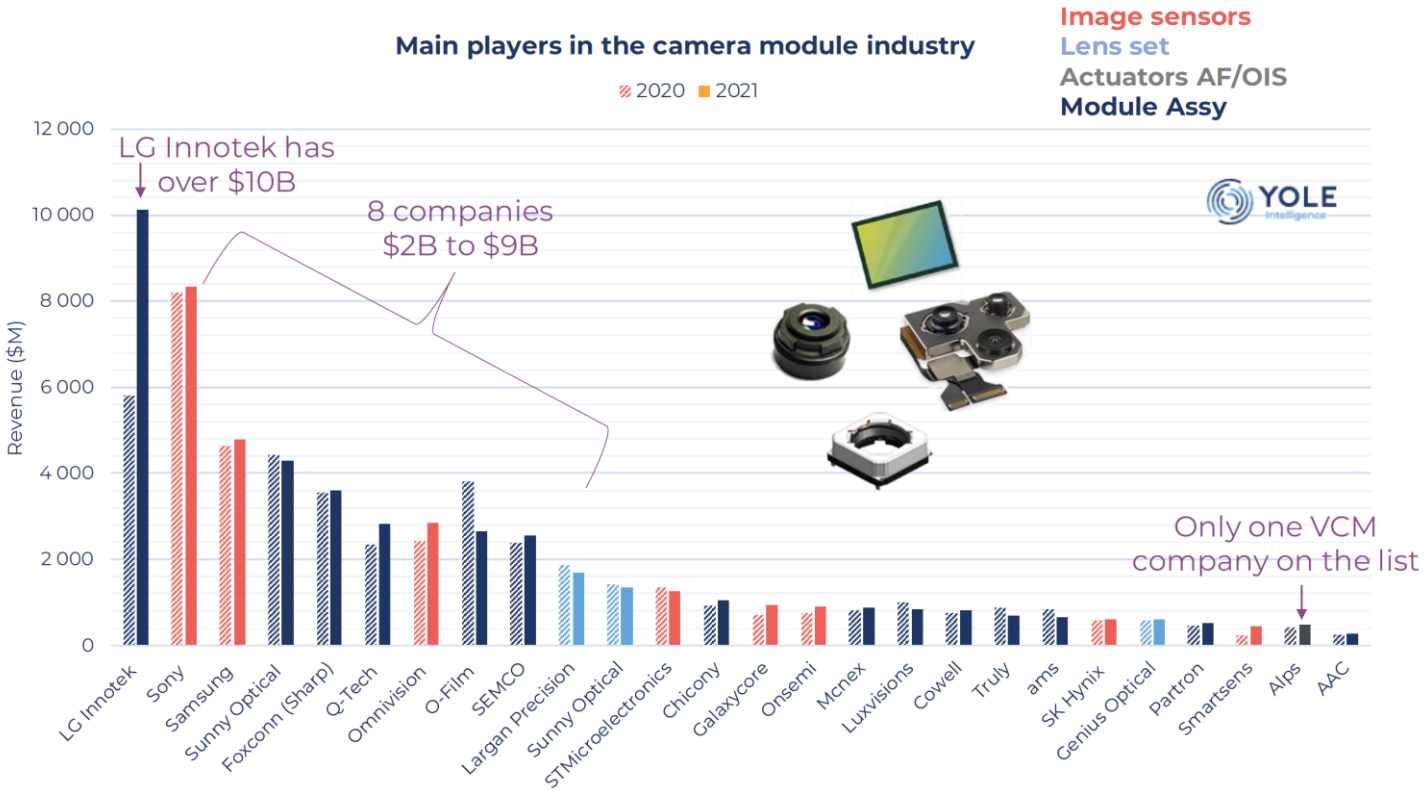
All these assembled by some camera modules manufacturers



courtesy of Oppo

The economy of camera modules





Top OEMs

	Apple	oppo	SAMSUNG	vivo	xiaomi
System OEM					
Module assembly	FOXCONN, SHARP, LG Innotek, COWELL	SAMSUNG ELECTRO-MECHANICS, SHINE, SUNNY OPTICAL TECHNOLOGY, Q Tech	partron, SAMSUNG ELECTRO-MECHANICS	SUNNY OPTICAL TECHNOLOGY, TRULY, Q Tech	SAMSUNG ELECTRO-MECHANICS, OFILM, Q Tech, SUNNY OPTICAL TECHNOLOGY
AF & OIS VCM	ALPS, Nidec, MITSUMI	JAHWA, ZET, HOZEL, 皓泽电子, TDK	JAHWA, im, Haesung Optics, HYSONIC	TDK, MITSUMI, SHICOH	JAHWA, TDK
Optics	LARGAN, Kantatsu, GSEO	SUNNY OPTICAL TECHNOLOGY, SPY 星聚宇光学, JH	SEKONIX, LARGAN	LARGAN, SUNNY OPTICAL TECHNOLOGY	SUNNY OPTICAL TECHNOLOGY, 诚瑞光学 AAC OPTICS
Image Sensor	SONY, life.augmented	SONY, OMNIVISION, SAMSUNG	SONY, SAMSUNG	SONY, OMNIVISION, SAMSUNG	SAMSUNG, SONY, OMNIVISION

Inside a Camera Module

- **The lens set made of lenses**
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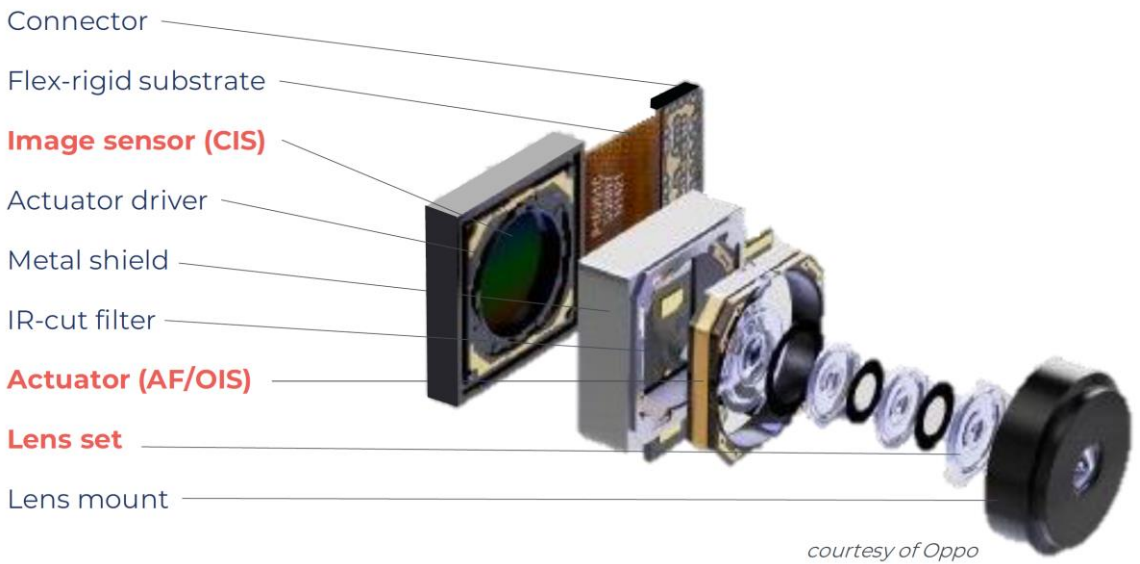
All these assembled by some camera modules manufacturers

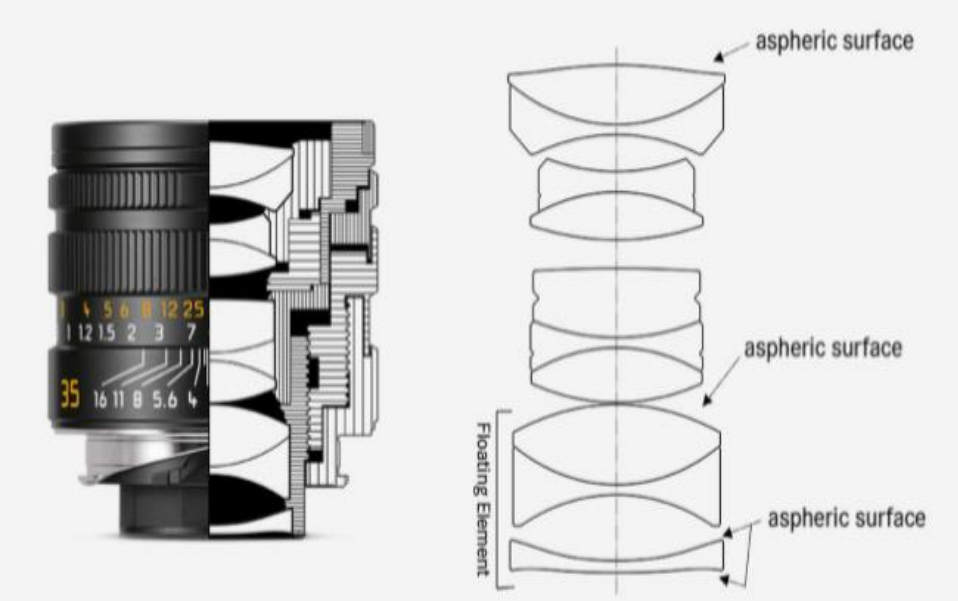


courtesy of Oppo

Typical lens design (main camera)

DSLR Lens

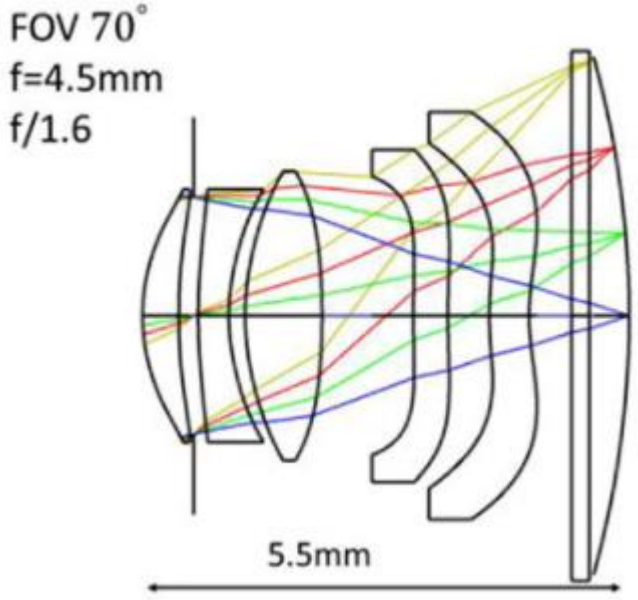
- Between 6 and 18 glass elements
- But mostly spherical



Smartphone lens (main camera)

- From 6 to 8 elements
- 1 glass, other plastics – all aspherical

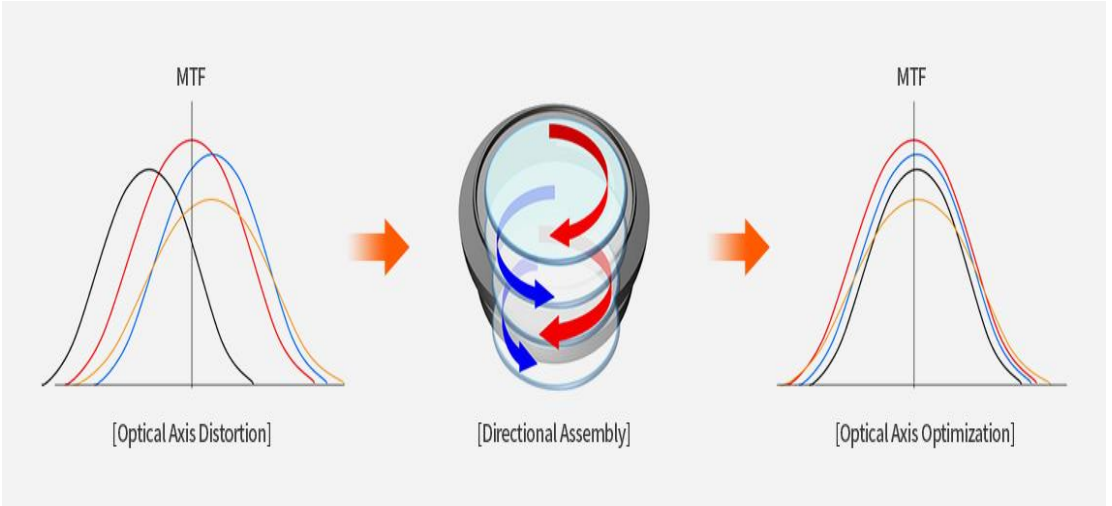
➔ The only (real) limits are:
diffraction & manufacturing



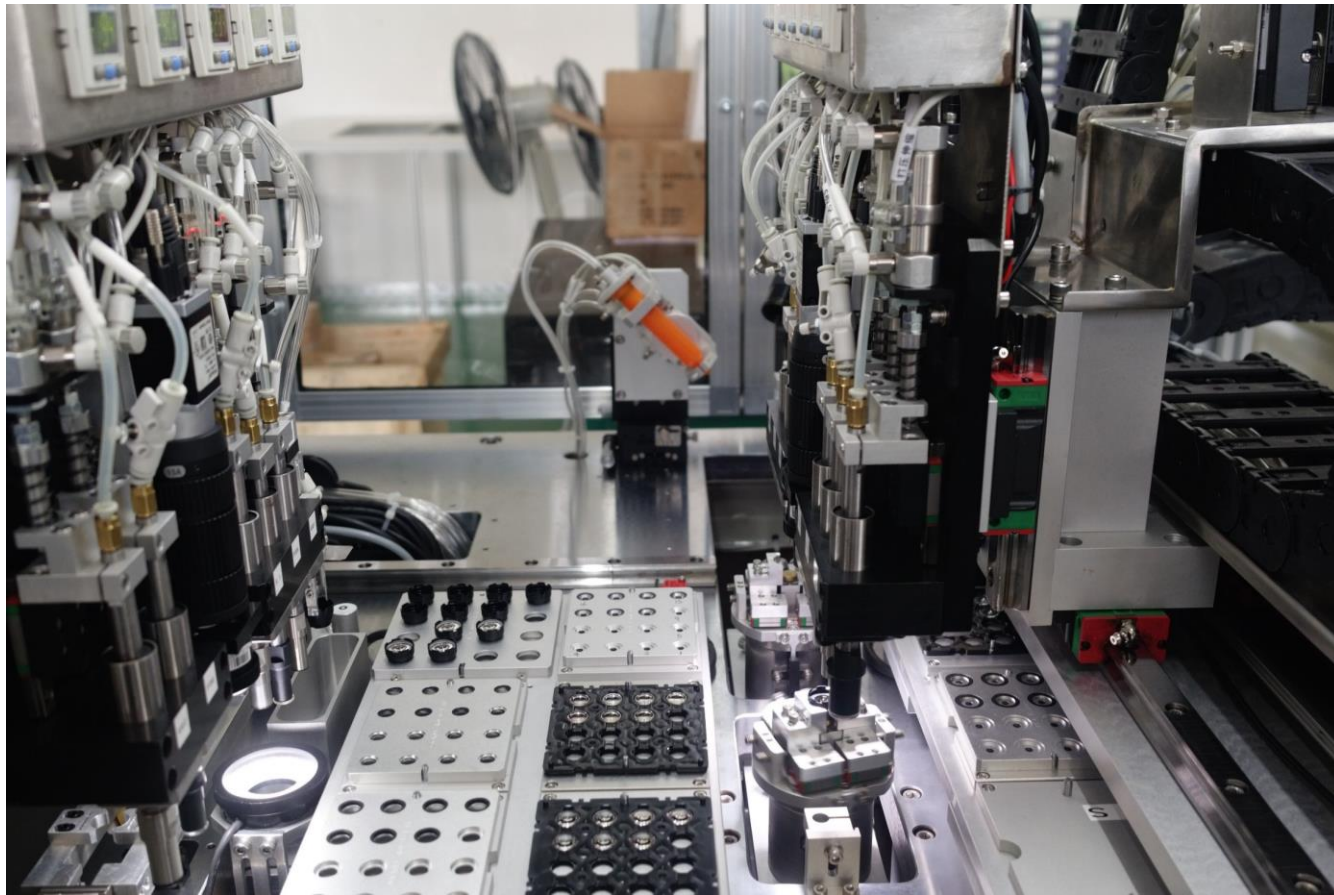
Lens elements manufacturing

- Molded plastic lenses
  - Very sensitive and somehow unpredictable
- Controls every 4hours:
  - For each lens elements, each cavity and each mold : surfaces are measured

Lens elements manufacturing



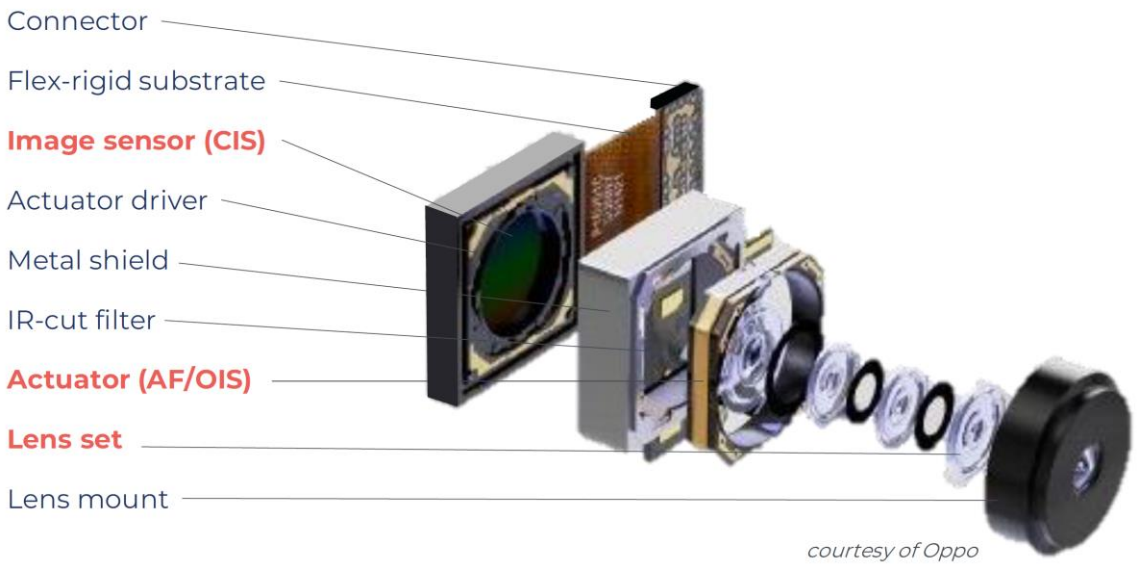
- Molded plastic lenses
  - Very sensitive and somehow unpredictable
- Controls every 4hours:
  - For each lens elements, each cavity and each mold : surfaces are measured
- Pairing and clocking process
  - decided every 4 hours…
  - so that default of one element is compensated by the other elements…



Inside a Camera Module

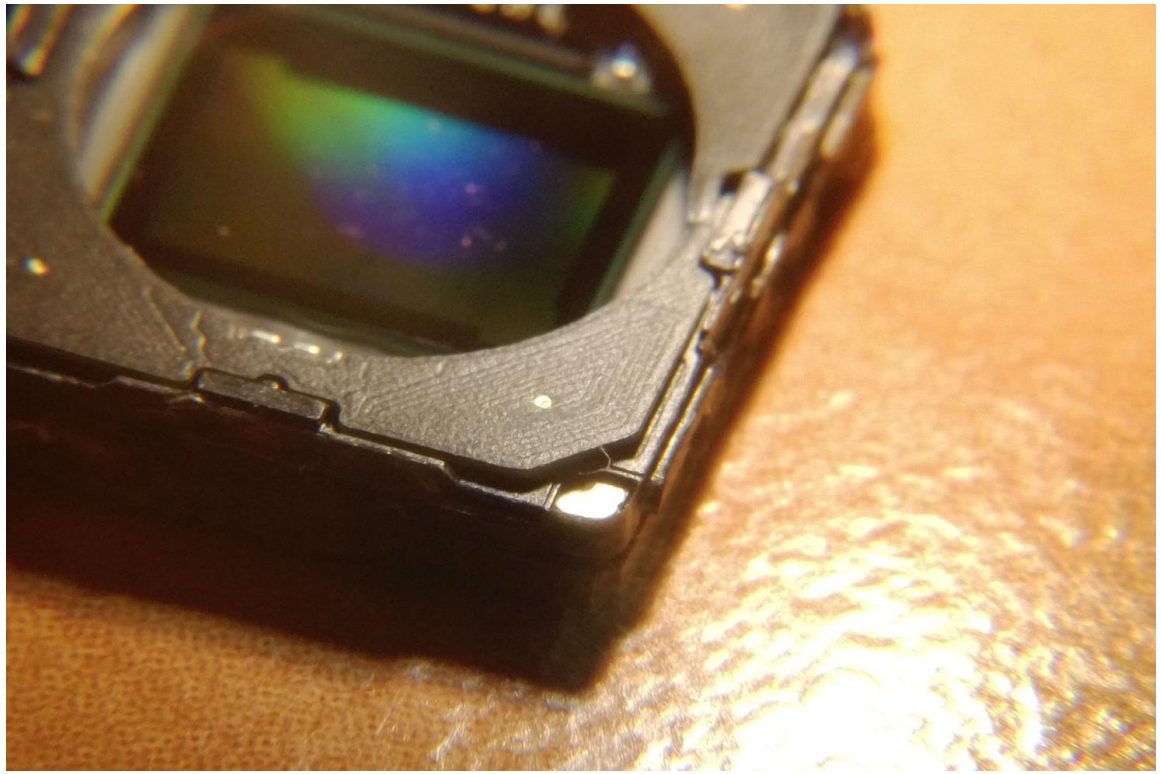
- The lens set made of lenses
- **The actuators (AF/OIS)**
- The image Sensor

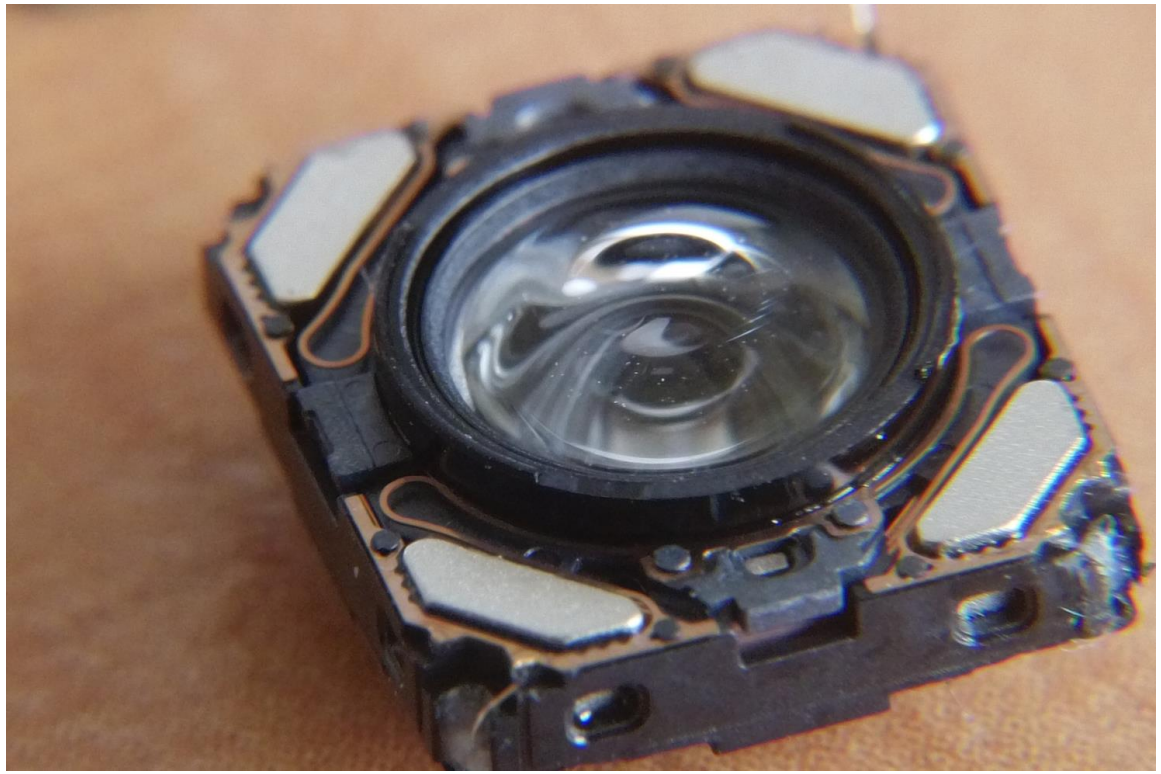
All these assembled by some camera modules manufacturers



courtesy of Oppo

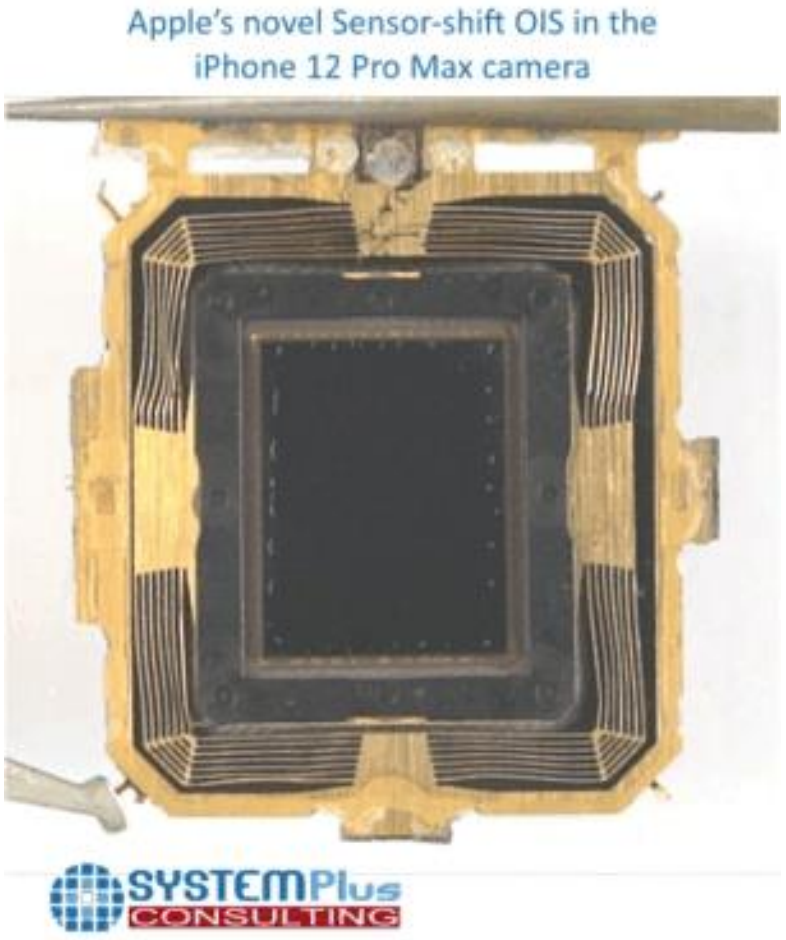
Camera modules manufacturers – beyond lens technologies





Exemple: iphone7 OIS & AF

Apple Sensor Shifthttps://www.reverse-costing.com/teardown-notes/apples-novel-sensor-shift-ois-iphone-12-pro-max-ca/



https://www.reverse-costing.com/teardown-notes/apples-novel-sensor-shift-ois-iphone-12-pro-max-ca/

Suppliers / other components

- IMU
  - Gyroscope is needed for OIS
    - Accelerometer is needed for AF and to un-bias Gyro
    - Magneto is needed to un-bias accelerometer
    - Temperature and barometric is needed to un-bais magneto
  - 6+ axis system (Gyro+Acc+Magneto+Temp+Baro) @ 10KHz.
  - Main actors :
    - Invensense
    - Bosch
    - Alps

Suppliers / Other components

- TOF (Time Of Flight)
  - For 3D, but also for AF and “bokeh effect”
  - Main actors :
    - ST Micro
    - Espros
    - Infineon

- Flash
  - LED or multi-LED

- Color sensor / Ambiant light
  - Light metering, ambient color (with IR), light flicker detection, etc…
  - Main actors :
    - ST Micro
    - AMS

ST VD6281

Inside a Camera Module

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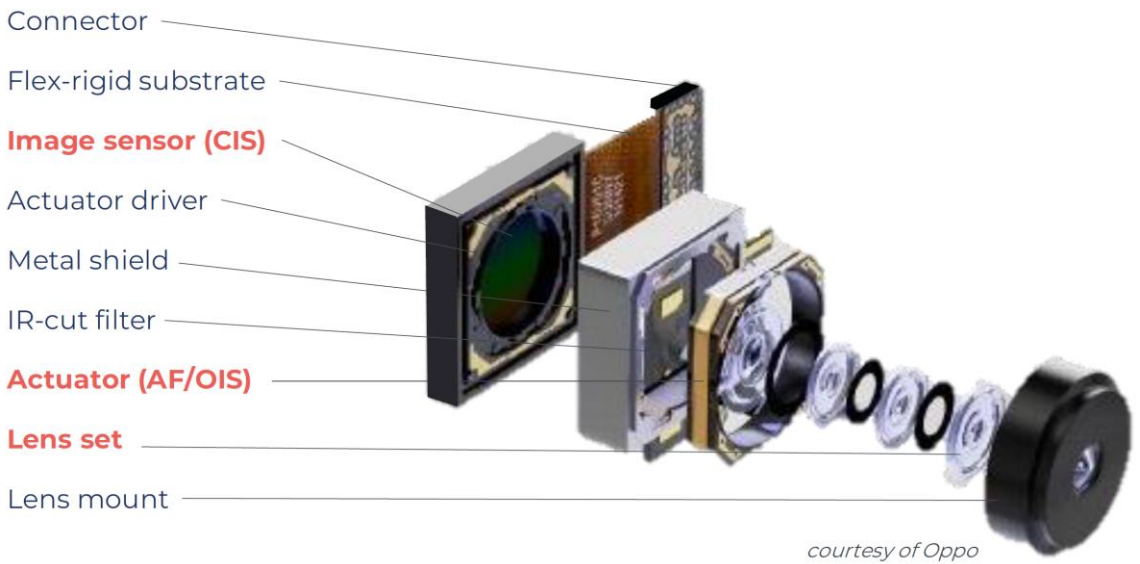
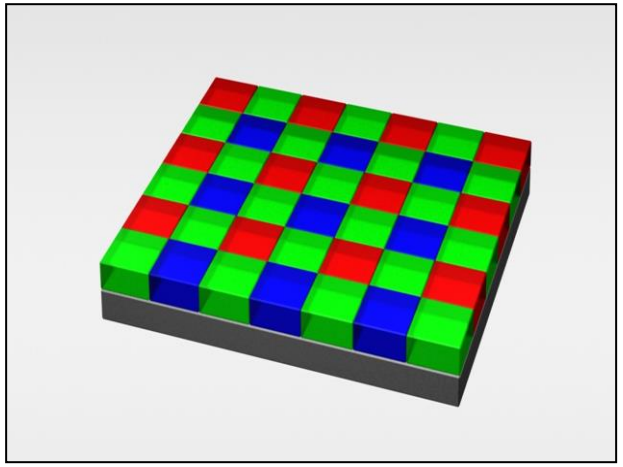
- The actuators (AF/OIS)
- **The image Sensor**

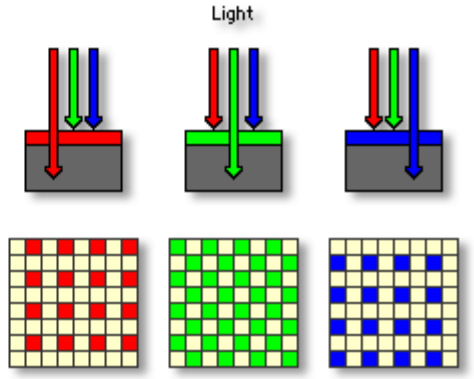
All these assembled by some camera modules manufacturers



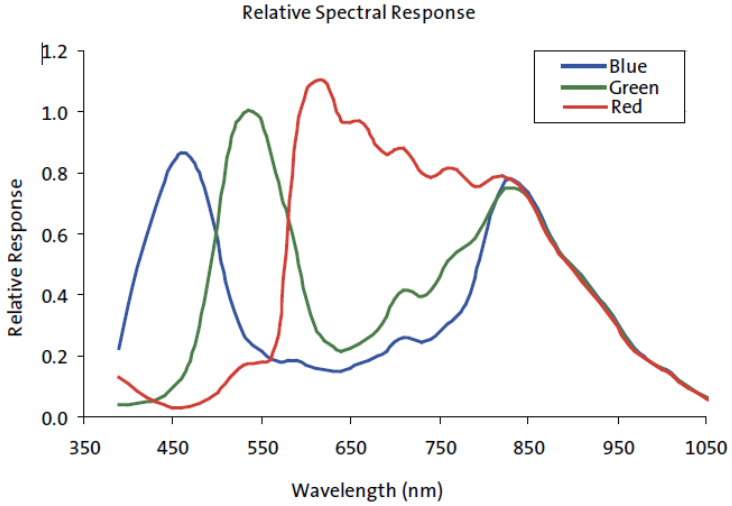
courtesy of Oppo

The image sensor





Bayer pattern (Eastman Kodak 1976)



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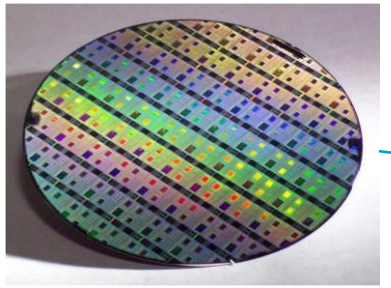
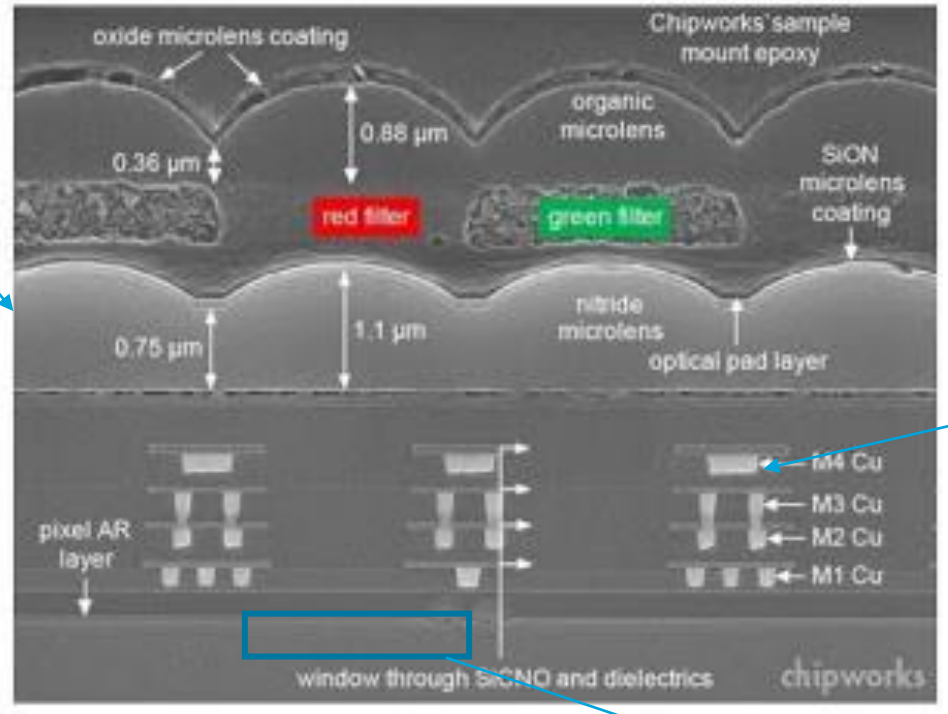
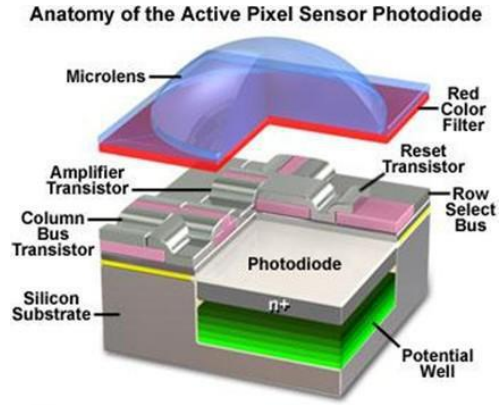
The image sensor

Micro lenses

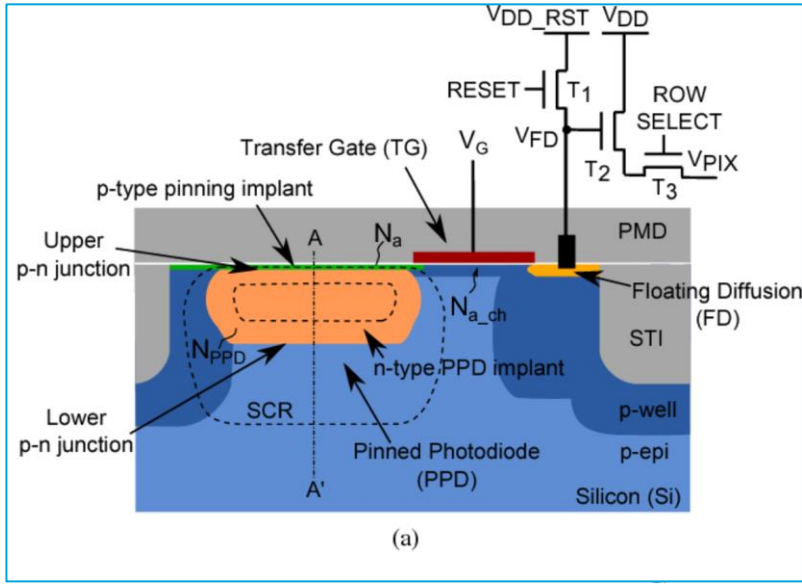
Color filters







Communication lines

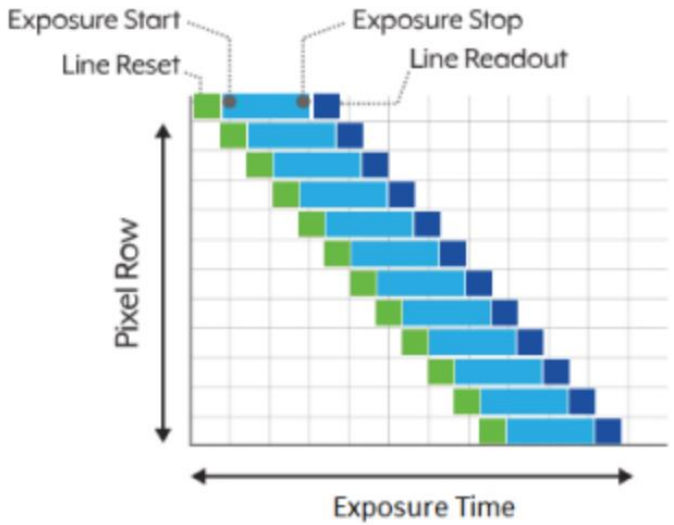


A classic silicon design:

- Photo sensitive area and a full well capacity to store e-
- 4 gates per pixels (4T) to transfer e- to communication lines

Pixel read out and electronics rolling shutter

Each row is read one after the other, and on each row: each pixel is read one after the other.



From top to bottom ➔ delay

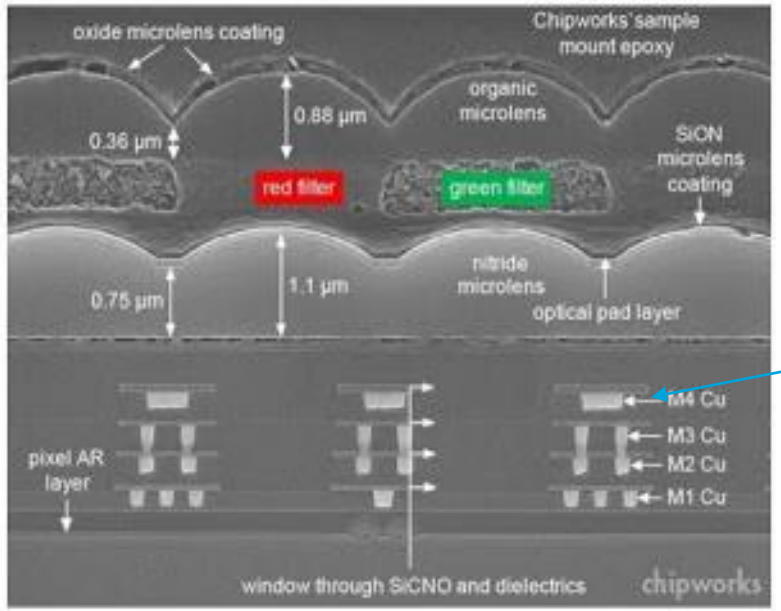
This delay decreases with pixels throughput increase
@1Gpixels/s delay is about 20ms for a 48Mpix sensor.

Pixel technologies

Photo sensitive area and Gates at the same layer

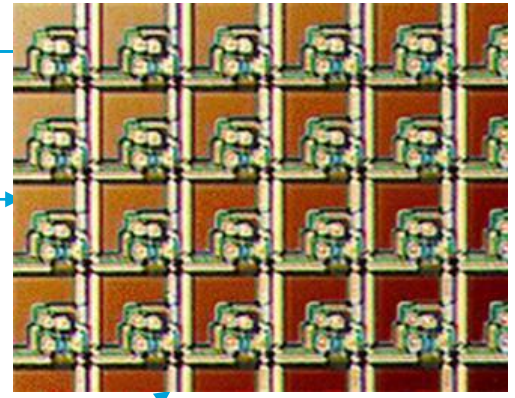
Communication lines are above and make “shadows” (or diffraction)

This makes **pixel pitch reduction** a nightmare…

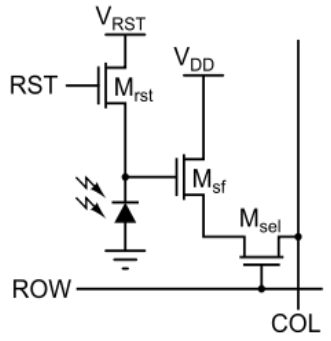


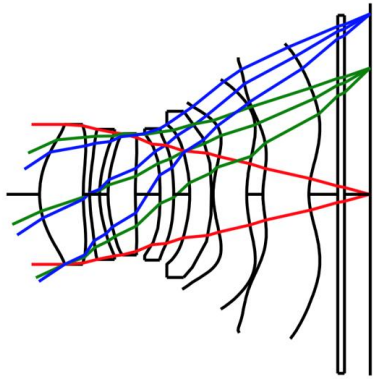
Gates

Photosensitive area

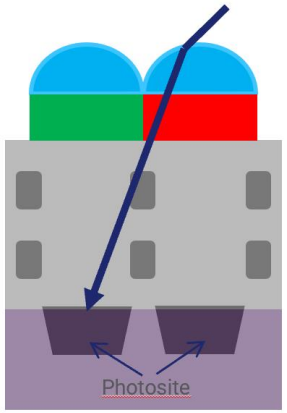


Communication lines





Large incident angles



Crosstalk

Color Lens Shading

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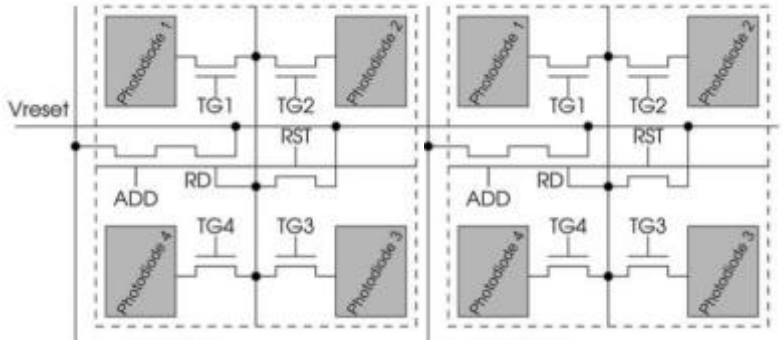
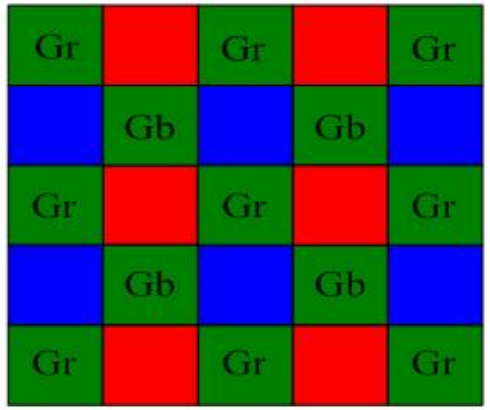
Pixel technologies

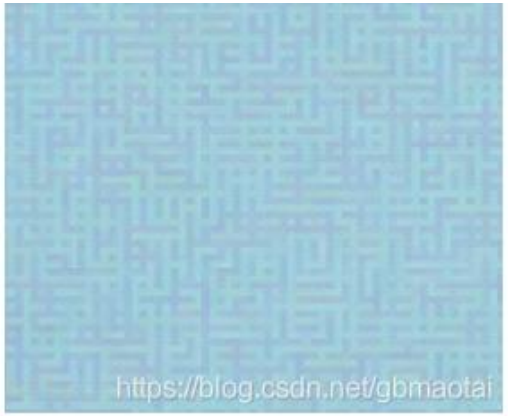
➔ Share communication lines and some gates ➔ 1.75T



Increase photosensitive part ☺
Smaller pixel pitch allowed (even below 1um) ☺

Asymmetrical pixels.
Gr and Gb : different spectral response! ☹





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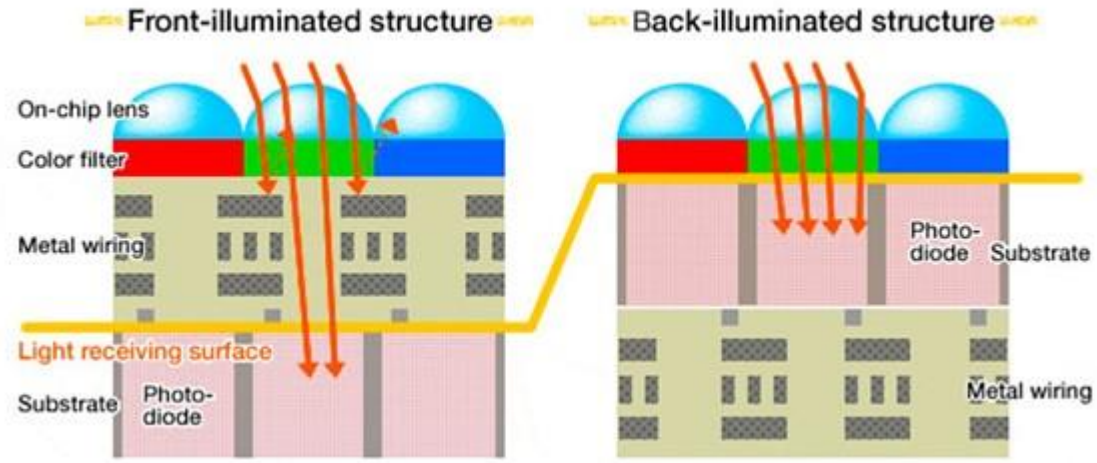
DXO

Front Side Illuminated / Back Side Illuminated / stacked

- From FSI to BSI (2012)

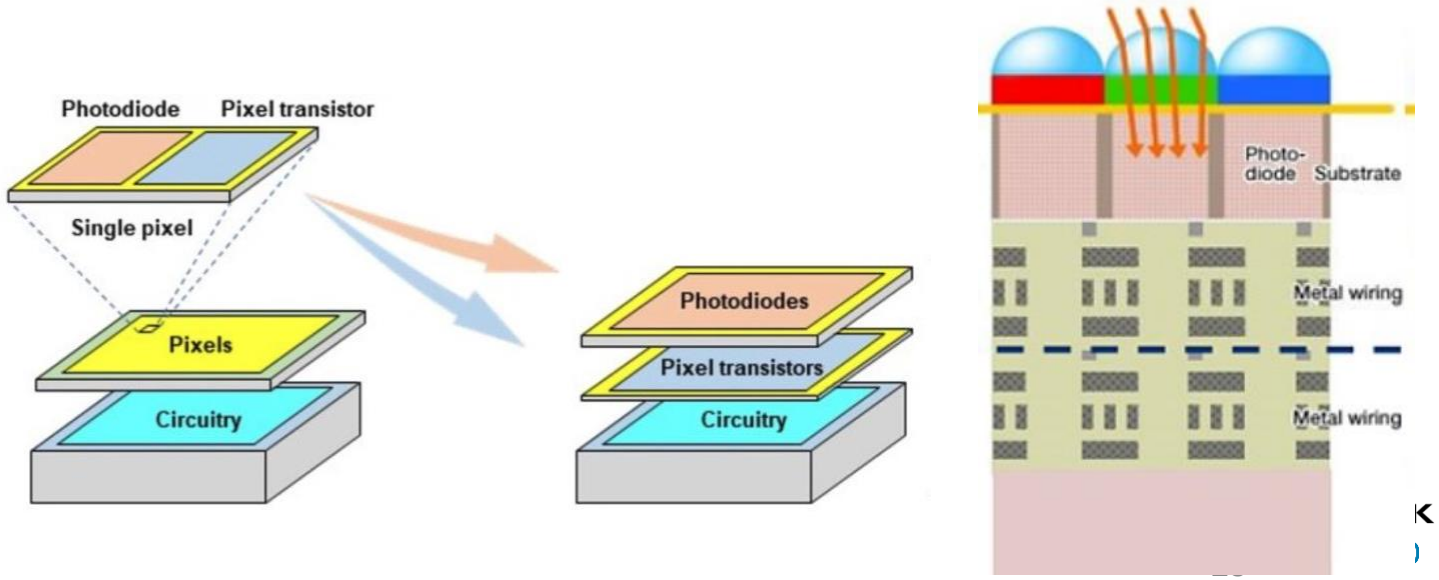
Metal layers are not an issue any-longer



- From BSI to Stacked BSI

Global shutter possible. (by adding a memory layer)

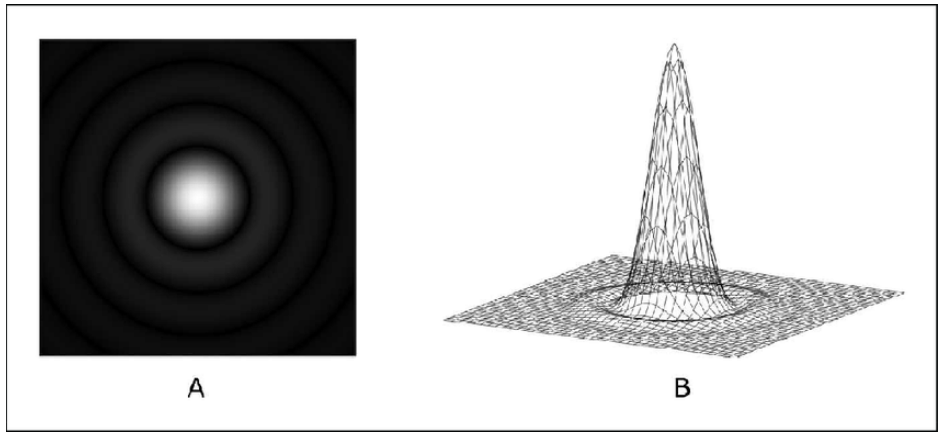
One day : single gate per pixel! ➔ more sensitivity



Note : Pixel pitch and diffraction limit

- Diffraction : r = $1.22\,\lambda\,f\#$ = ~0.65 f#

Aperture	Wave length cut-off (µm) at 530nm
2.8	1.82*2
2.0	1.3*2
1.4	0.9*2

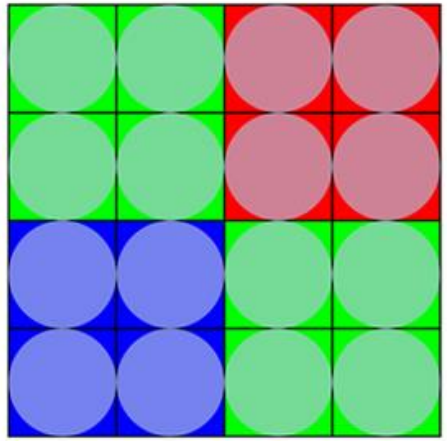


➔Aperture must be very wide for small pixels

Bayer variants…

Quad structure

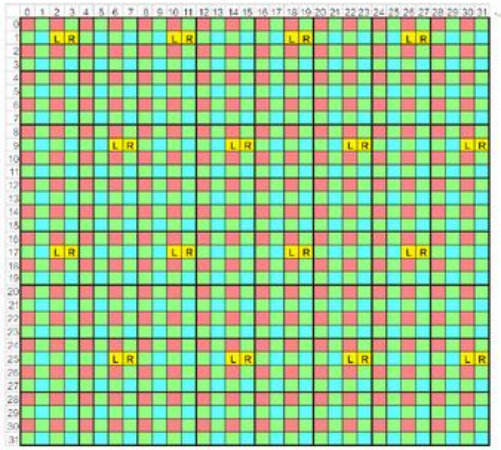
Back to bayer when used half resolution.

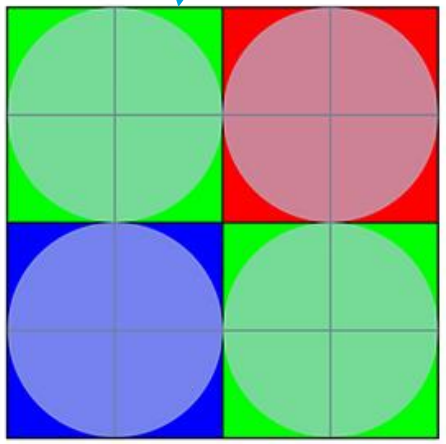


Masking or specific micro lenses for AF statistics
“Phase pixels” or “dual pixels”

	Bayer		Quad	
Structure	Shield	Shield	2x1OCL	Dual PD
Density	1.5%	3%	3%	50% (green pixel)

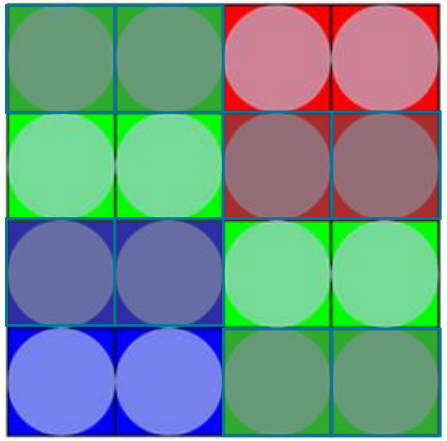
1Block = 32 pixel x 32



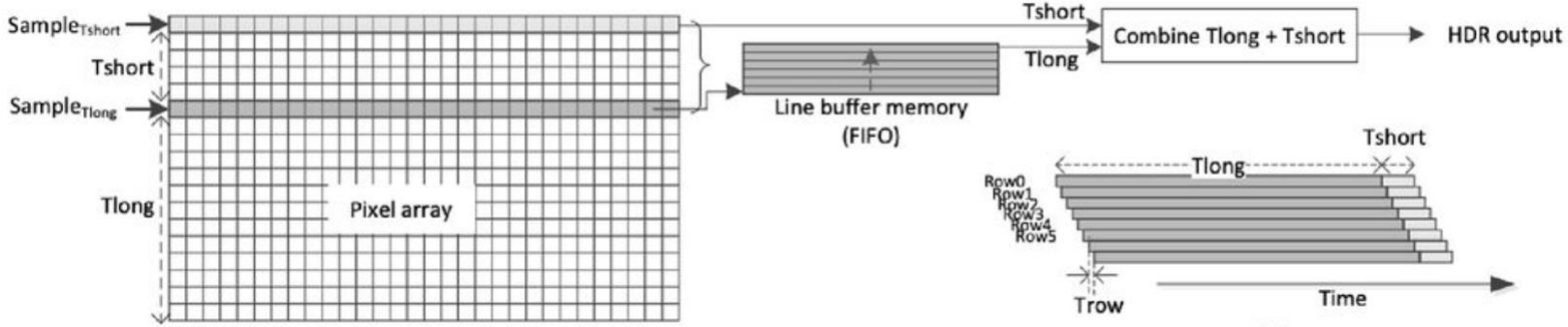


Bayer variants… and HDR

Q-HDR
(quad structure with various sensitivities)



Stagged HDR
(dual read out)



Smartphone’s Camera ingredients

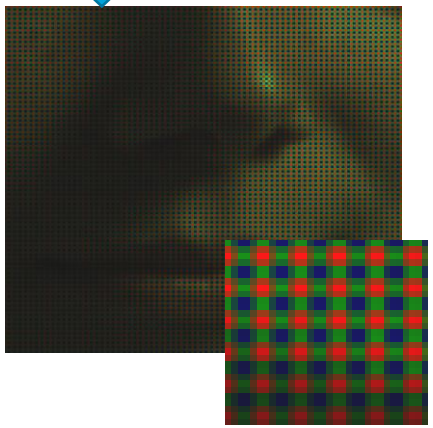
- Camera module(s)
  (and other sensors)

- **The image processing**
  - **Introduction (chipset/SW)**
  - Camera controls
  - The “image pipe”
  - Architecture

RAW → RGB

Scene

Camera module & al



RAW Image(s)

Camera controls

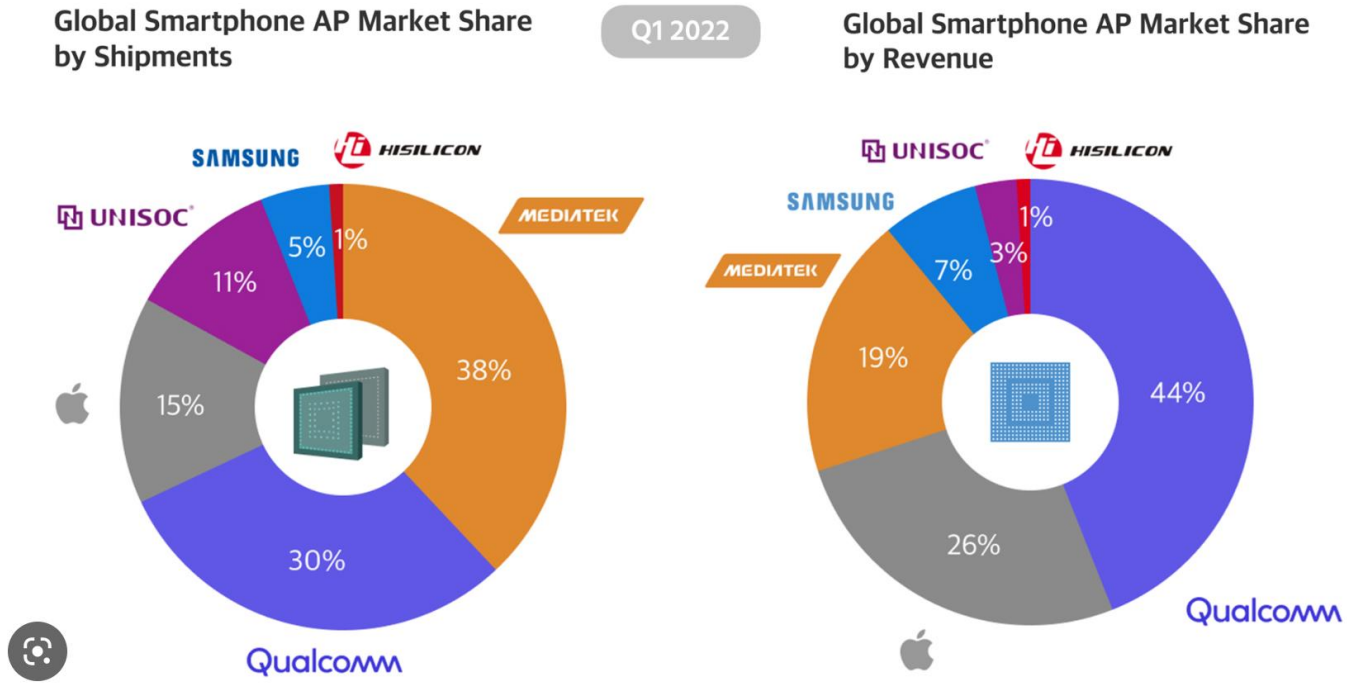
Image processing Pipe

ISP

YUV/ Final image (Photo or Video)

Suppliers / Chipset

- Proprietary solutions:
  - Apple (A series)
  - Samsung (Exynos)
  - Huawei Hisilicon (Kirin)
- Off the shelves:
  - Qualcomm (QTI Snapdragon)
  - Mediatek (MTK Dimensity)
  - Unisoc
- Kind of mixed:
  - Google : QTI + Tensor
  - Oppo : QTI or MTK + Marisilicon



An example : Snapdragon 8gen2

Artificial Intelligence

Qualcomm® Adreno™ GPU

Qualcomm® Kryo™ CPU

Qualcomm® Hexagon™ Processor

- Fused AI Accelerator Architecture
- Hexagon Tensor Accelerator
- Hexagon Vector eXtensions
- Hexagon Scalar Accelerator
- Hexagon Direct Link
- Support for mix precision (INT8+INT16)
- Support for all precisions (INT4, INT8, INT16, FP16)
- Micro Tile Inferencing

Qualcomm® Sensing Hub

- Dual AI Processors for audio and sensors
- Always-Sensing camera

5G Modem-RF System

Snapdragon® X70 5G Modem-RF System

- 5G mmWave and sub-6 GHz, standalone (SA) and non-standalone (NSA) modes, standalone mmWave and mmWave-sub6 dual connectivity, FDD, TDD
- mmWave: 8 carriers, 2x2 MIMO
- Sub-6 GHz: 4x4 MIMO
- Qualcomm® 5G AI Suite
- Qualcomm® AI-Enhanced Signal Boost
- Qualcomm® 5G PowerSave Gen 3

Camera

Qualcomm Spectra™ Image Signal Processor

- Cognitive ISP, Triple 18-bit ISPs
- Up to 36 MP triple camera @ 30 FPS with Zero Shutter Lag
- Up to 64+36 MP dual camera @ 30 FPS with Zero Shutter Lag
- Up to 108 MP single camera @ 30 FPS with Zero Shutter Lag
- Up to 200 Megapixel Photo Capture

AI-based face detection, auto-focus, and auto-exposure

Rec. 2020 color gamut photo and video capture

Up to 10-bit color depth photo and video capture

8K HDR Video Capture + 64 MP Photo Capture

10-bit HEIF: HEIC photo capture, HEVC video capture

Video Capture HDR Formats: HDR10+, HDR10, HLG, Dolby Vision

8K HDR Video Capture @ 30 FPS

4K Video Capture @ 120 FPS

Slow-mo video capture at 720p @ 960 FPS

8K Video Playback @ 60 FPS

Engine for Visual Analytics 3.0

CPU

Kryo CPU

- 64-bit Architecture
- 1 Prime core, up to 3.2 GHz[2]
  - Arm Cortex-X3 technology
- 4 Performance cores, up to 2.8 GHz
- 3 Efficiency cores, up to 2.0 GHz

Visual Subsystem

Adreno GPU

- Real-time Hardware Accelerated Ray Tracing
- Snapdragon Game Post Processing Accelerator
- HDR gaming (10-bit color depth, Rec. 2020 color gamut)
- Snapdragon Shadow Denoiser
- API Support: OpenGL® ES 3.2, OpenCL™ 2.0 FP, Vulkan® 1.3
- Hardware-accelerated H.265 and VP9 decoder
- HDR Playback Codec support for HDR10+, HDR10, HLG, and Dolby Vision

Security

Platform Security Foundations, Trusted Execution

Environment & Services, Secure Processing Unit (SPU)

Trust Management Engine

Qualcomm® wireless edge services (WES) and

ISP : ~3G pixels per second, @ 10K+ ops/pixels ➔ 30 Tops/s
GPU : ~1280 Alu(FP32x3) @ 700Mhz ➔ ~2.7 Tops/s
Made possible thx to 4nm node.

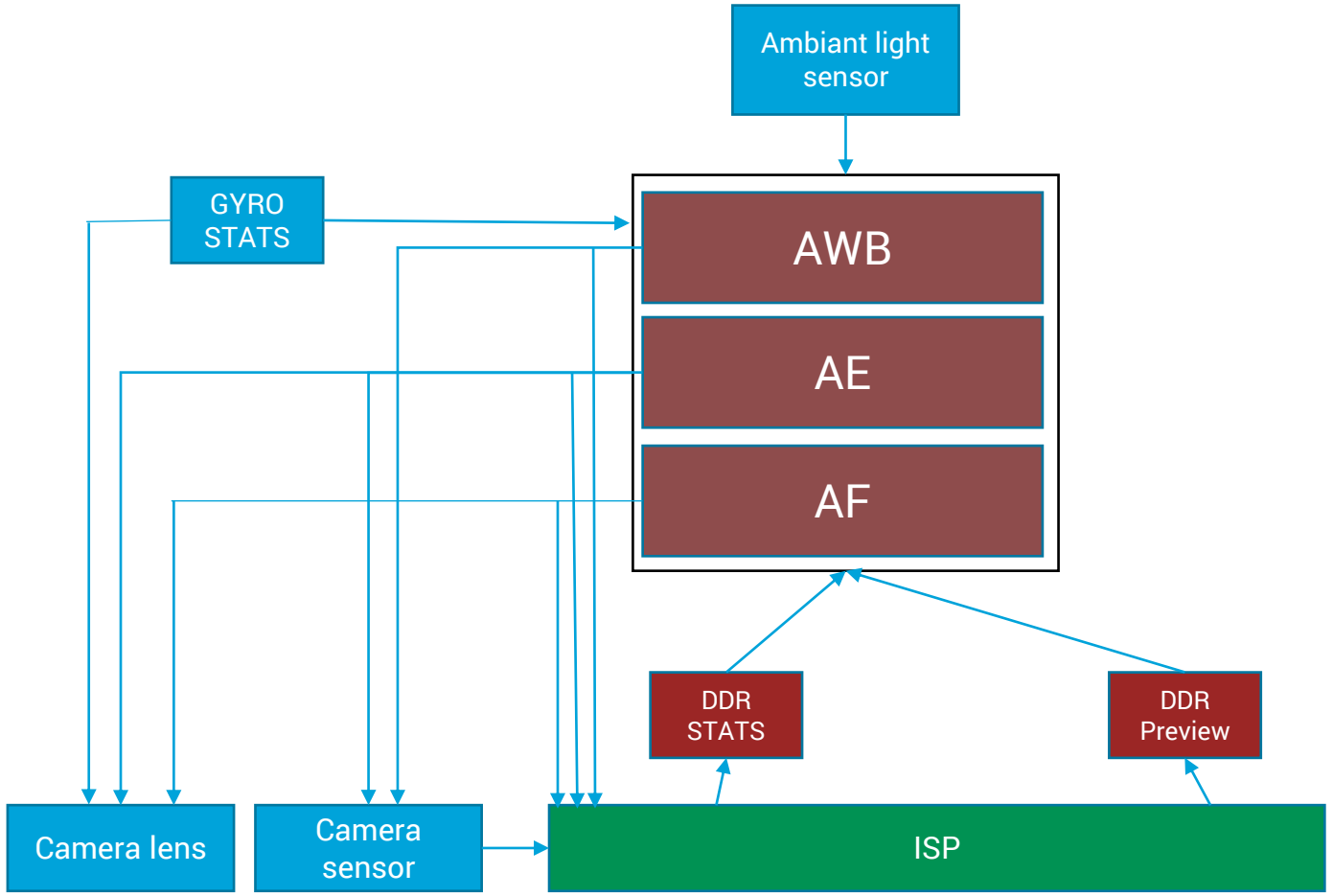
Smartphone’s Camera ingredients

- Camera module(s)
  (and other sensors)

- **Chipset (ISP)**
  - Introduction (chipset/SW)
  - **Camera controls**
  - The “image pipe”
  - Architecture

Camera Controls or “3A”

- Auto Exposure
- Auto Focus
- Auto White Balance

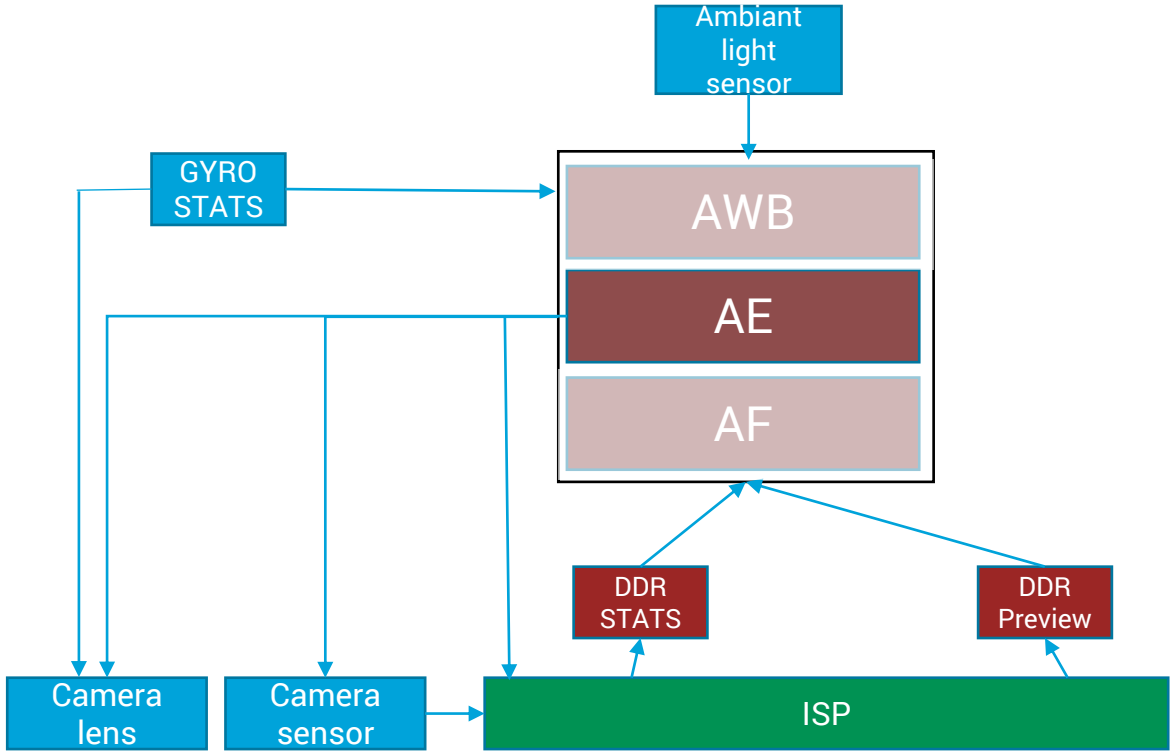


Auto Exposure

Inputs:
- Image statistics (histogram)
- Ambiant light statistics (flicker)
- Gyro data (camera motion)
- Image preview analysis (face detection, scene motion etc…)

Outputs:
- **Time exposure** (sensor)
- Iris (if any to the lens)
- **ISO** (digital&analog gains green channel)
- Flash control
- Switch to HDR mode with exposures bracketing strategy
- Switch to night mode

Objectives:
- Tradeof between SNR, bright clipping and motion blur
- No light flicker



Auto Exposure

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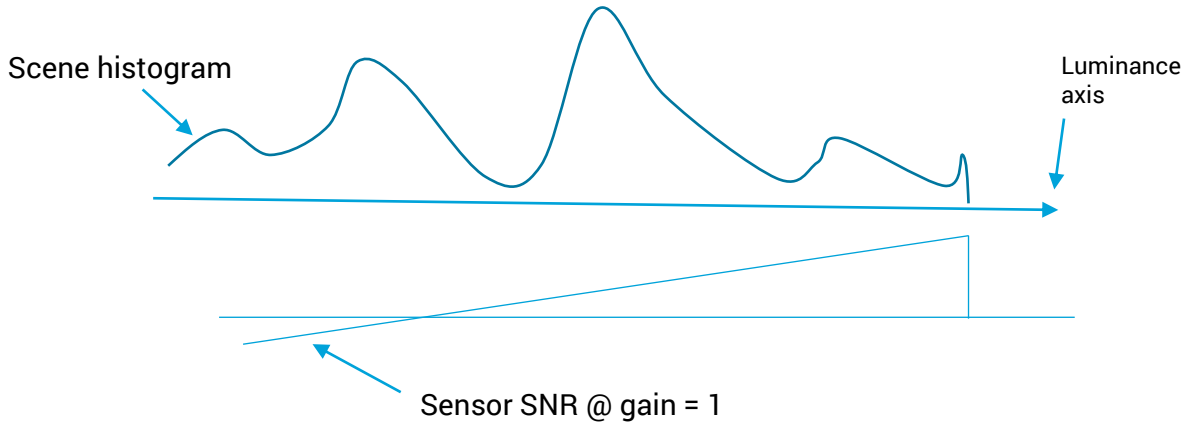

#1 : Exposure time adjusted at saturation
➔ No clipped areas. ☺ but… image too dark and SNR too low for most part ➔ impossible to digitally relight the picture

Auto Exposure

Inputs:
- Image statistics (histogram)
- Ambiant light statistics (flicker)
- Gyro data (camera motion)
- Image preview analysis (face detection, scene motion etc…)

Outputs:
- **Time exposure** (sensor)
- Iris (if any to the lens)
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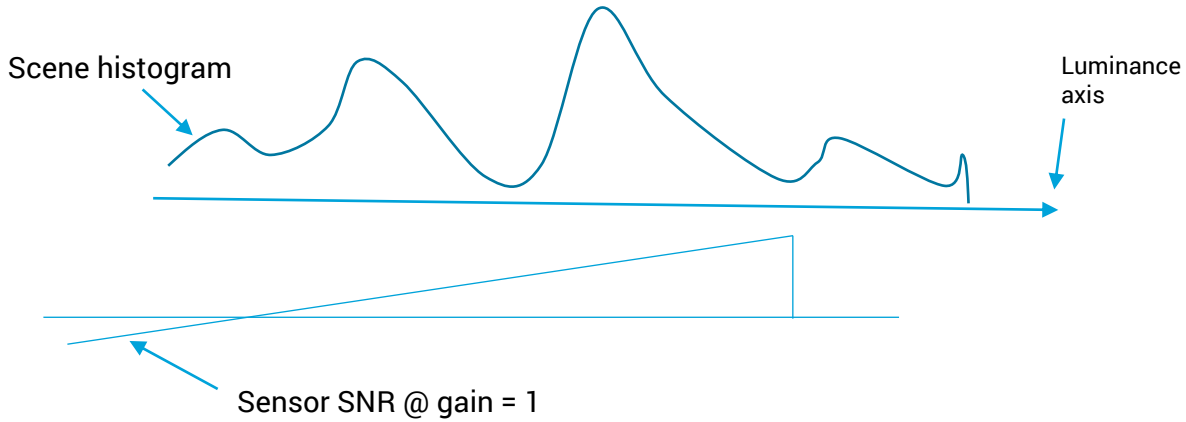


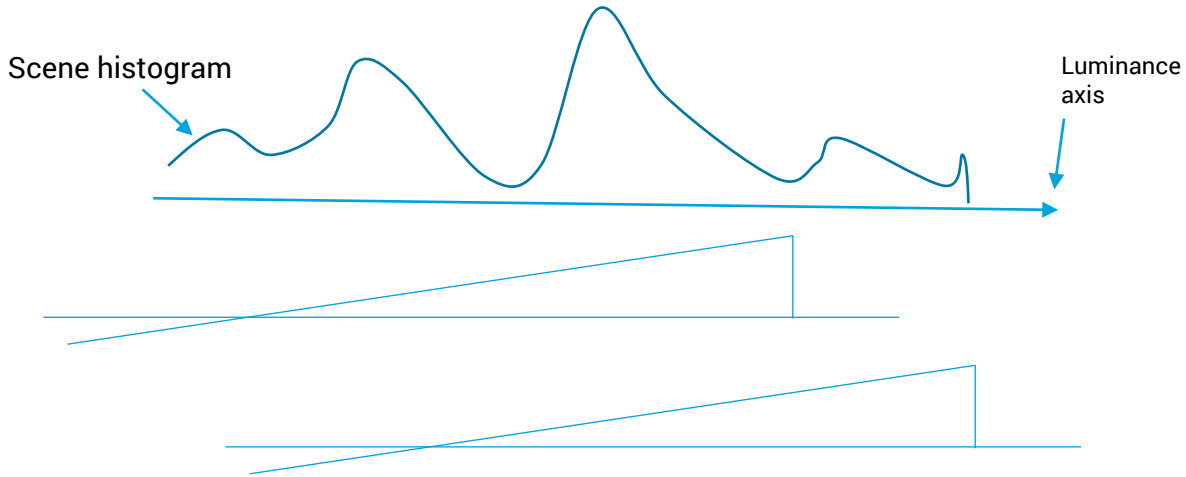
#2 : Exposure time adjusted for the main part:
➔ Overall good exposure and SNR but
High-light are clipped. Information lost, impossible to recover.

Auto Exposure

Inputs:
- Image statistics (histogram)
- Ambiant light statistics (flicker)
- Gyro data (camera motion)
- Image preview analysis (face detection, scene motion etc…)

Outputs:
- **Time exposure** (sensor)
- Iris (if any to the lens)
- **ISO** (digital&analog gains green channel)
- Flash control
- Switch to HDR mode with exposures bracketing strategy
- Switch to night mode

Objectives:
- **Tradeof between SNR, bright clipping and motion blur**
- No light flicker



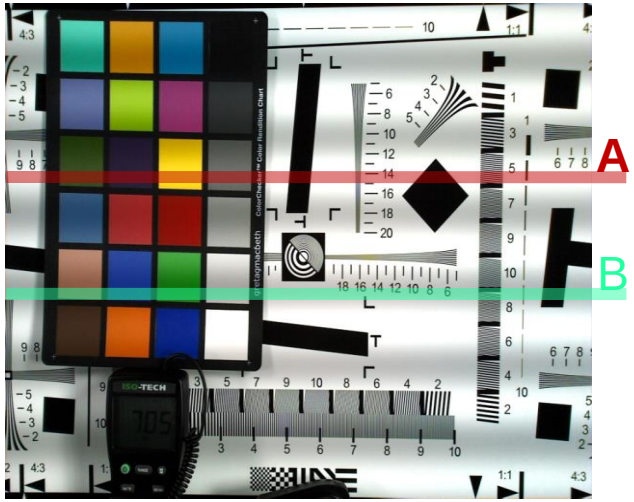
#3 : Switch to HDR strategy with two exposures.
➔ All parts are captured with reasonable SNR
But, two images to fuse, with possible motion in between…

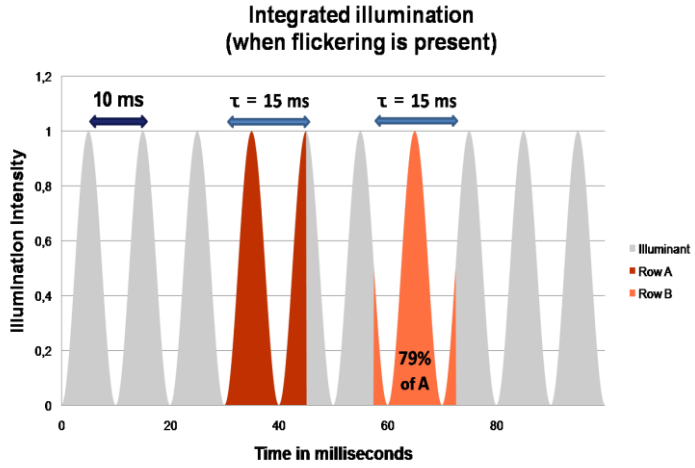
Auto Exposure

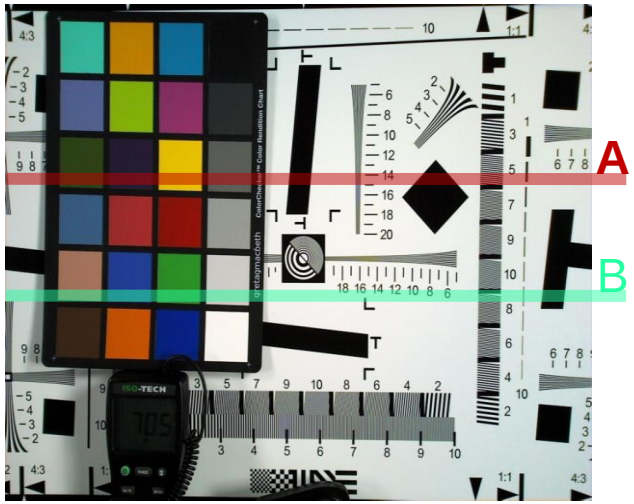
Inputs:
- Image statistics (histogram)
- Ambiant light statistics (flicker)
- Gyro data (camera motion)
- Image preview analysis (face detection, scene motion etc…)

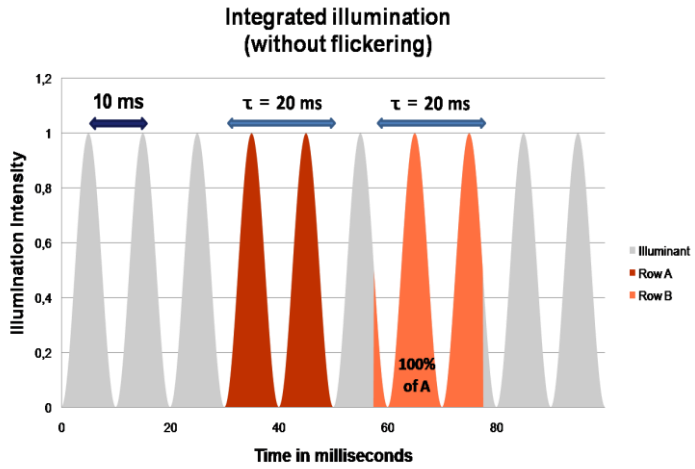
Outputs:
- **Time exposure** (sensor)
- Iris (if any to the lens)
- **ISO** (digital&analog gains green channel)
- Flash control
- Switch to HDR mode with exposures bracketing strategy
- Switch to night mode

Objectives:
- Tradeof between SNR, bright clipping and motion blur
- **No light flicker**









Auto White Balance

Inputs:

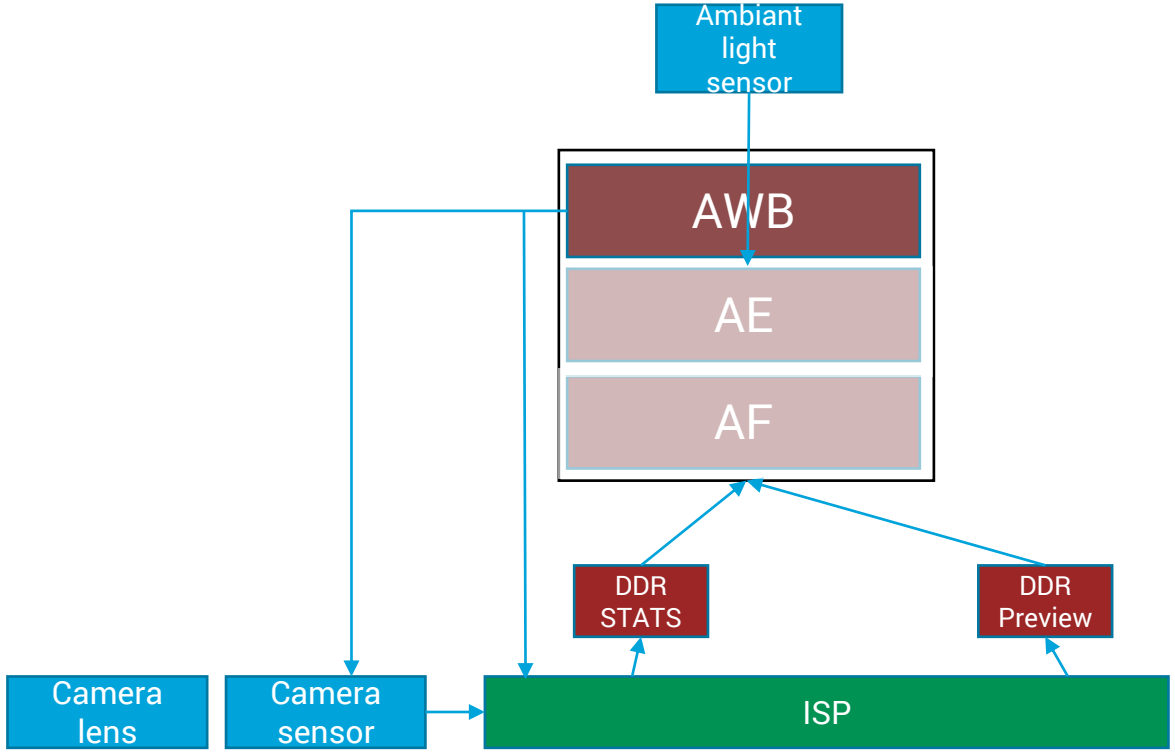
- Image statistics (histogram)
- Ambiant light statistics
- Image preview analysis (face detection, content analysis, etc…)

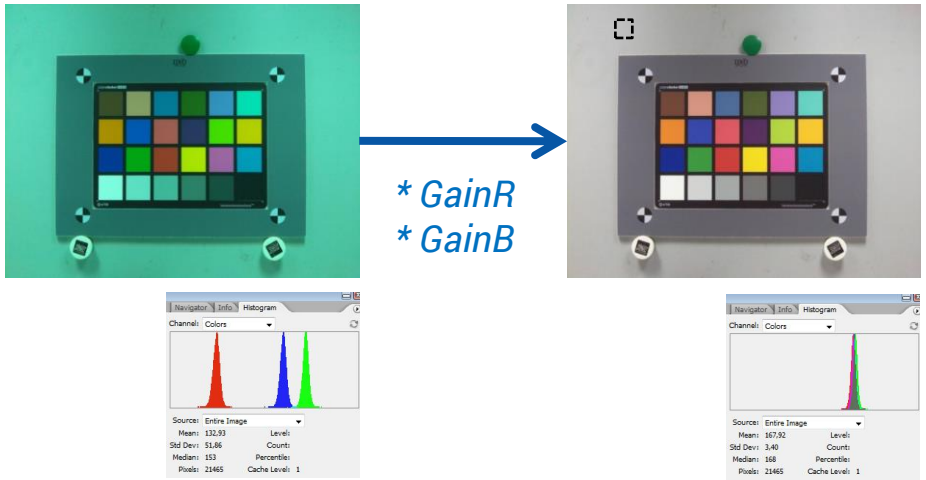
Outputs:

- 2 gains : Blue and Red gain (vs Green one)
- (additional option : color rendering maps)

Objective:

- “Get the colors right”





Auto White balance

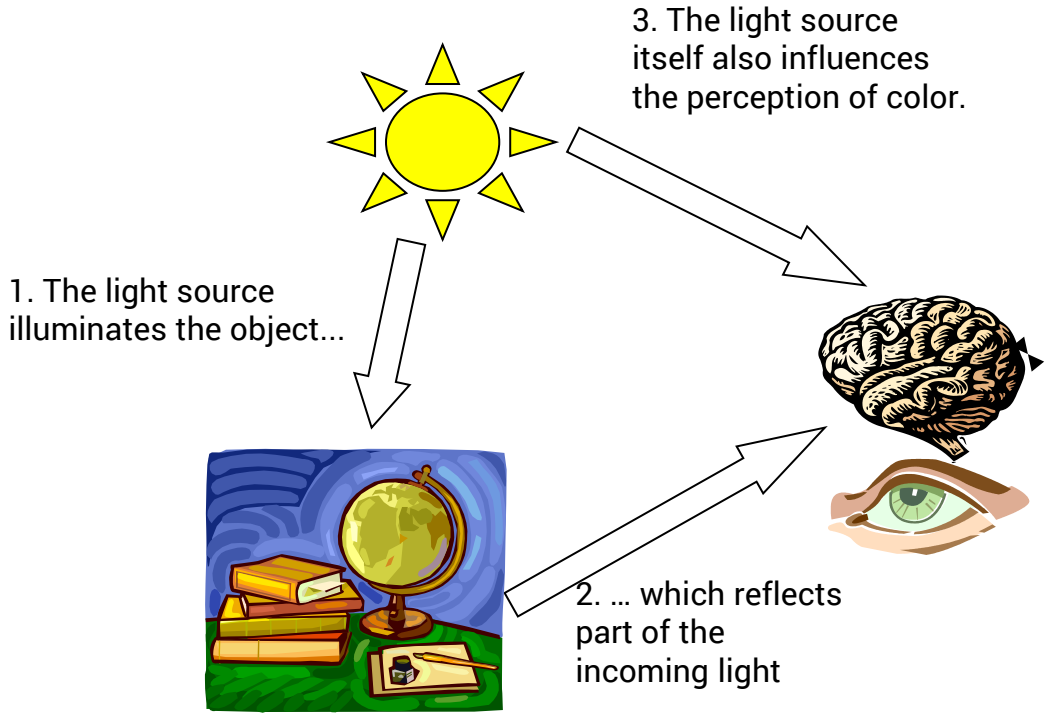
The « triangle of color »

(Perceived) color of an object is the result of an interaction between :

the light source,

the object and…

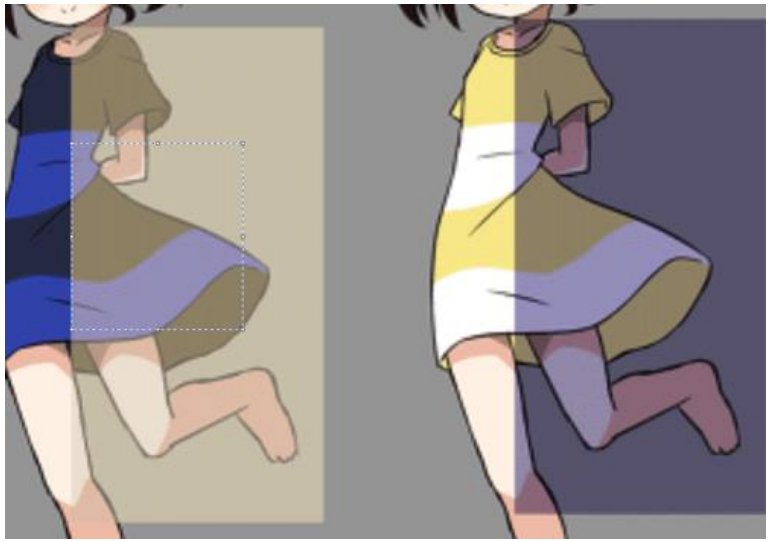
the human visual system.



White balance objective:

Get rendered colors by the camera to be independent from the illumination conditions

➔ Illuminant should be determined.



Auto White balance - which illuminant ?

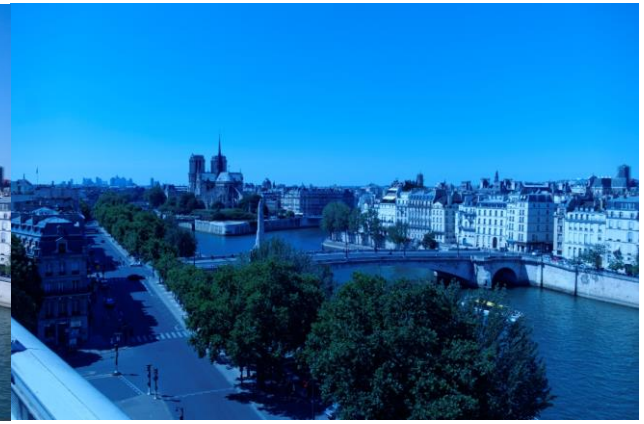
Shade

D65

D60

D55

Fluo40



Tungsten

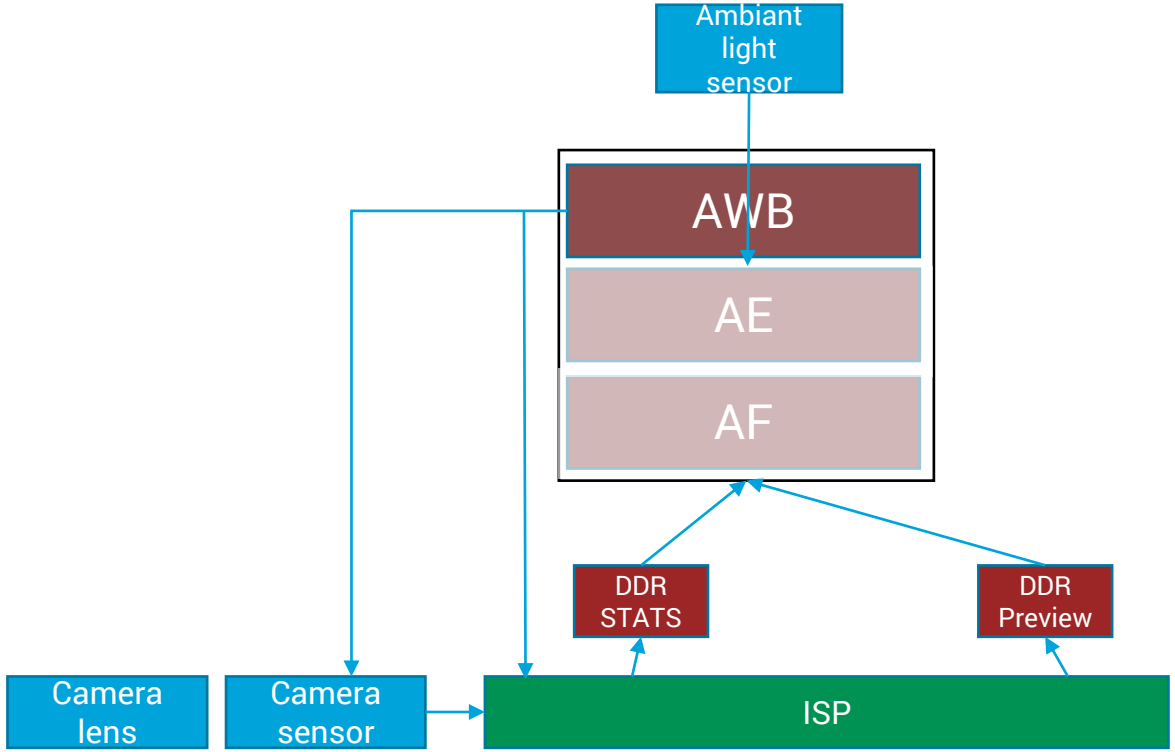
Auto White Balance

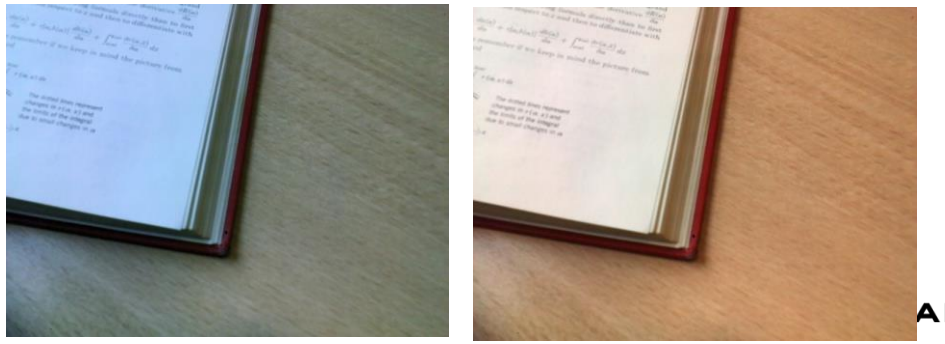
Inputs:
- Image statistics (histogram)
- Ambiant light statistics
- Image preview analysis (face detection, content analysis, etc…)

Outputs:
- 2 gains : Blue and Red gain (vs Green one)
- (additional option : color rendering maps)

Objective:
- “Get the colors right”

Not so simple and partly subjective…



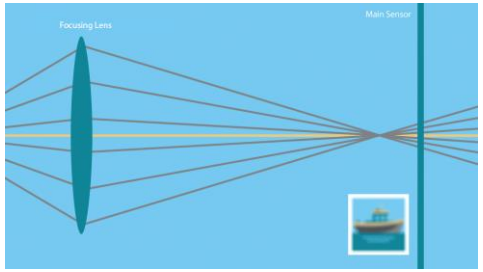


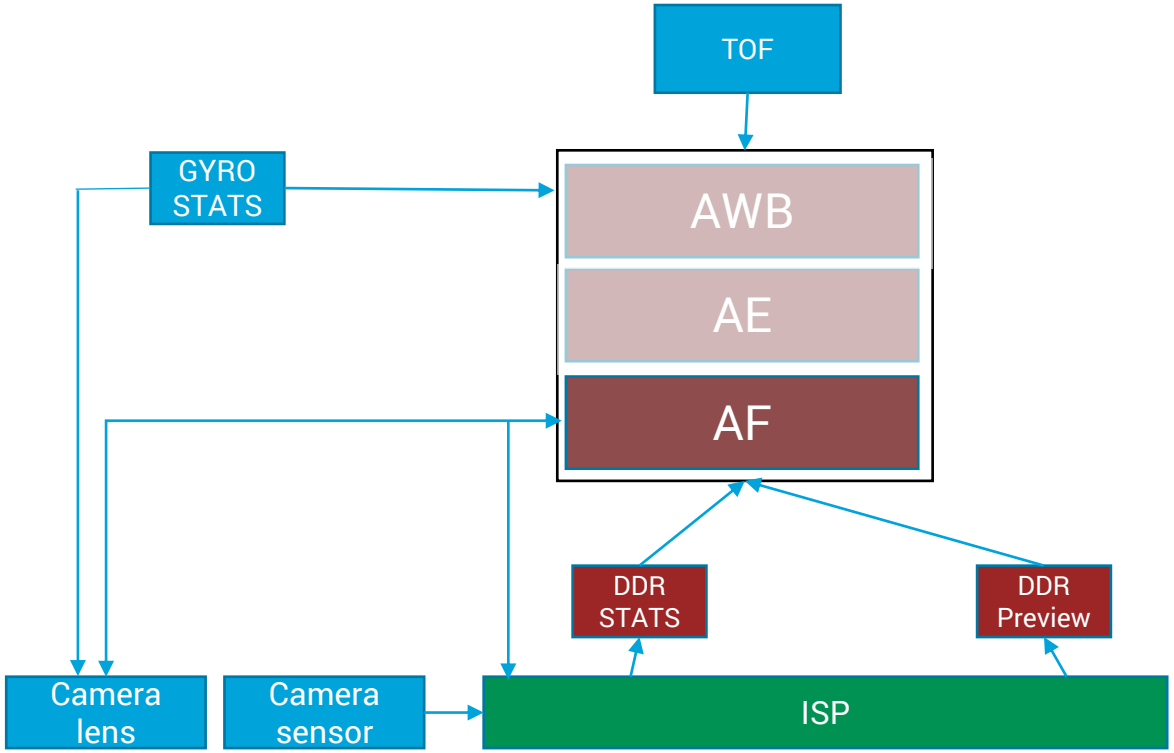
Auto Focus

Inputs:
- Image statistics, dual/phase pixels data.
- Image preview analysis (face detection…)
- TOF data
- Hall sensor data from lens' AF actuator or Gyro data (accelerometer)

Outputs:
- **Focus position for lens**
- Magnification factor for ISP

Objectives:
- Important part of the scene should be in focus.



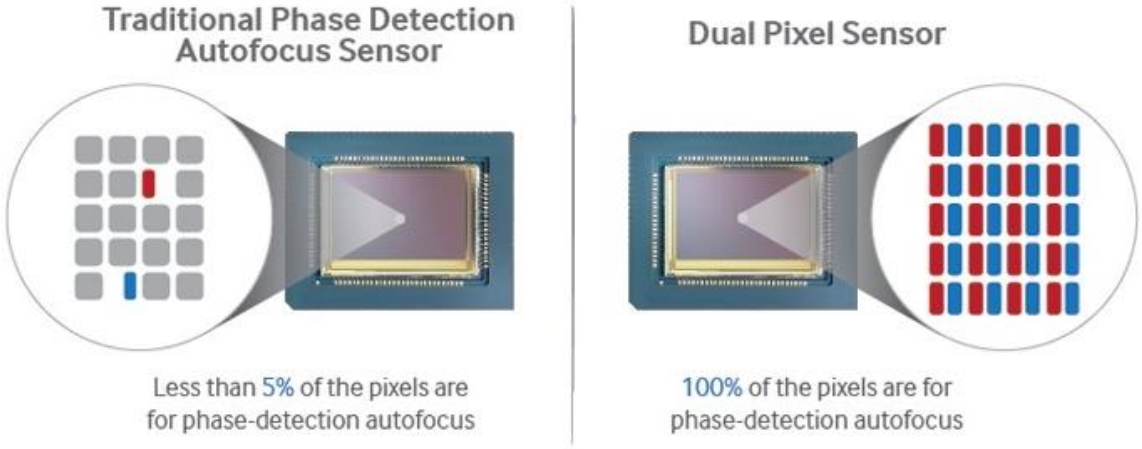


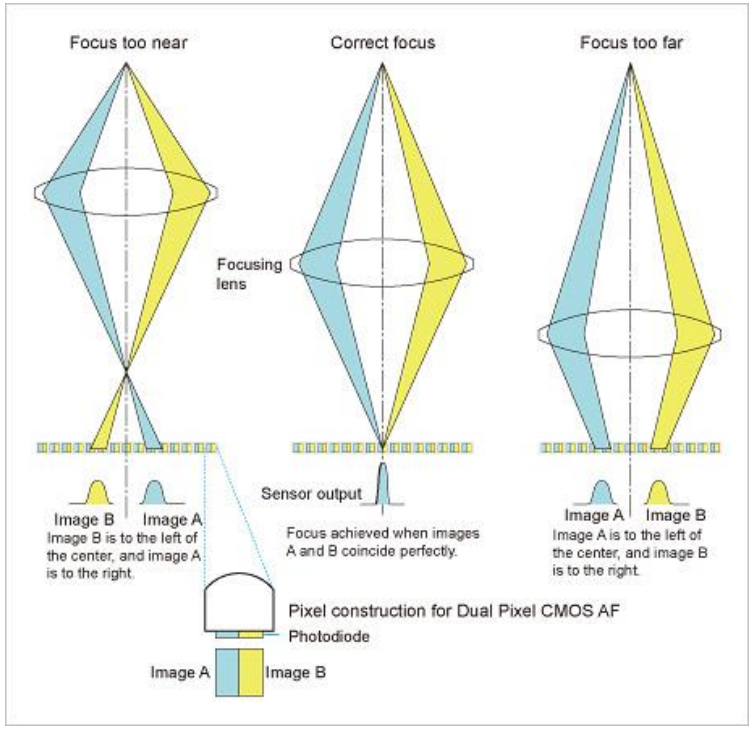
Auto Focus

Inputs:
- Image statistics, **dual/phase pixels data**.
- Image preview analysis (face detection…)
- TOF data
- Hall sensor data from lens' AF actuator or Gyro data (accelerometer)

Outputs:
- **Focus position for lens**
- Magnification factor for ISP

Objectives:
- Important part of the scene should be in focus.



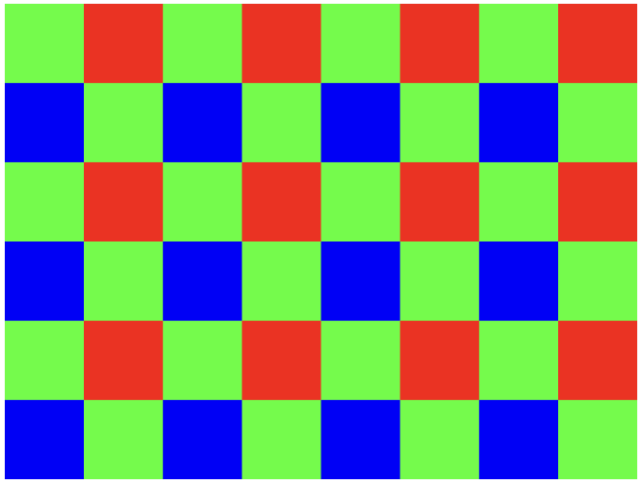


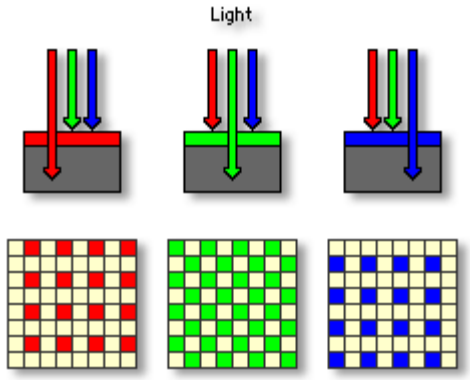
Smartphone’s Camera ingredients

- Camera module(s)
  (and other sensors)

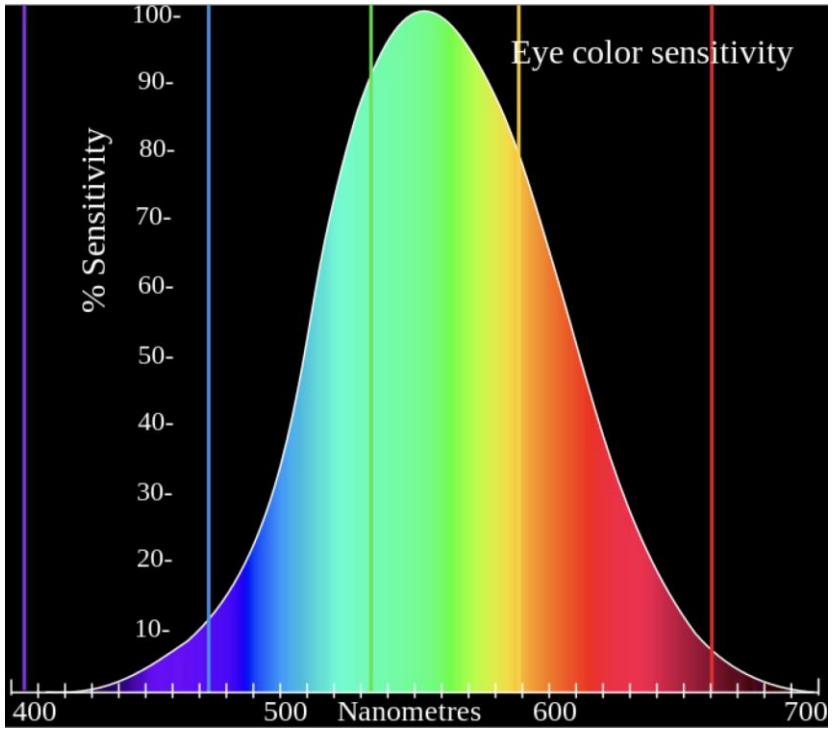
- **Chipset (ISP)**
  - introduction
  - Camera controls
  - **The “image pipe”**
  - Architecture

Color filter mosaic and demosaicing





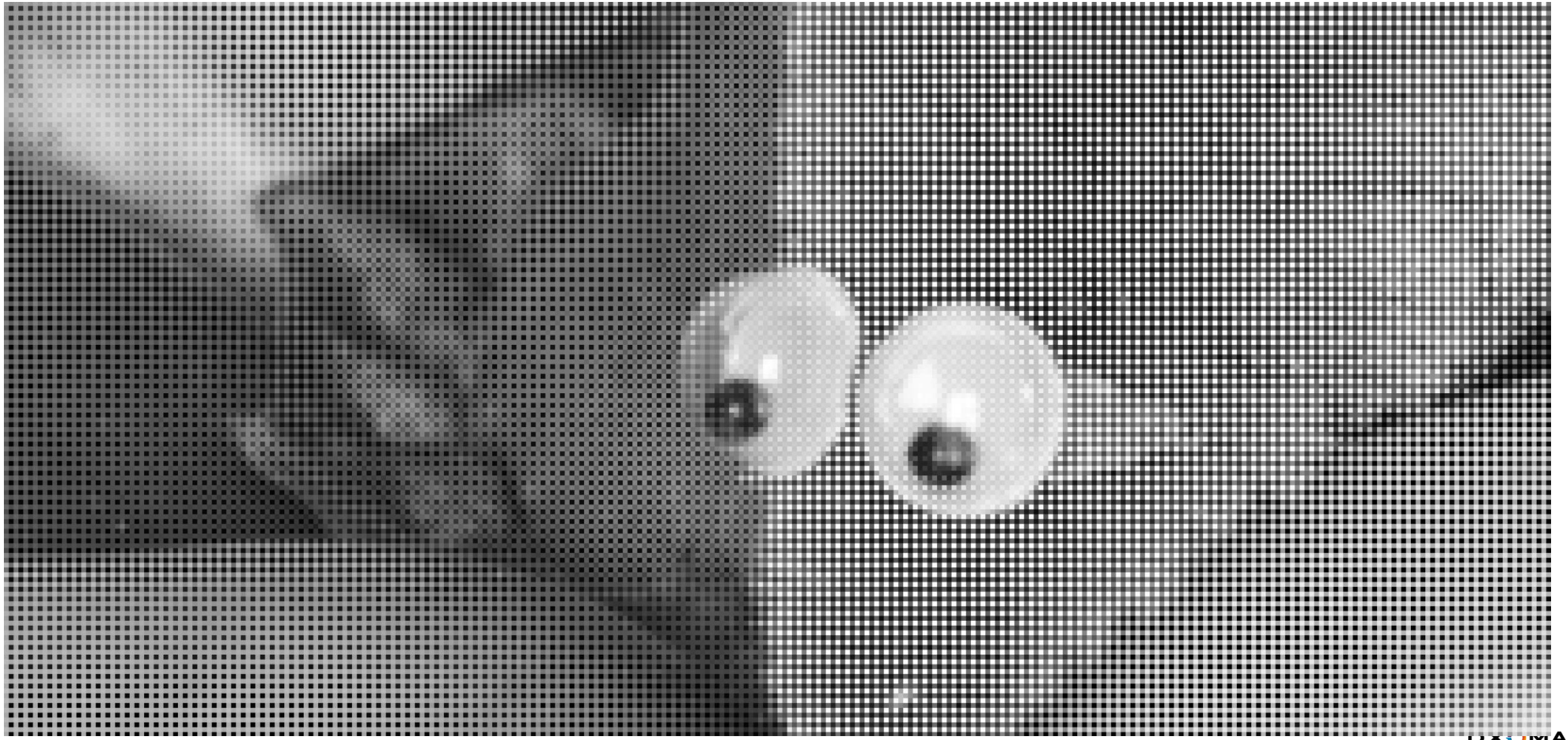
Bayer pattern (Eastman Kodak 1976)



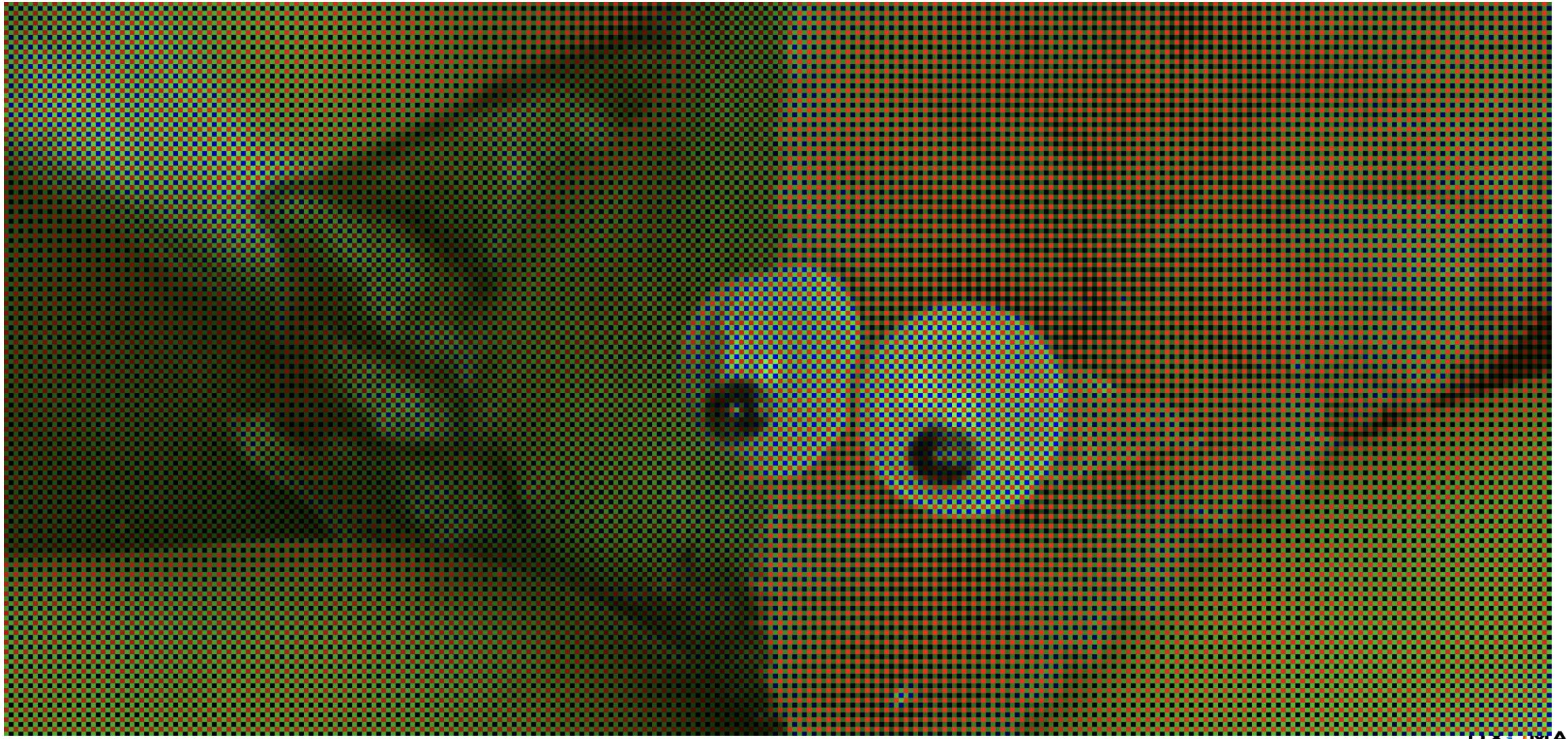
Spectral sensitivity of the human eye

DXOMARK
DXO

Sensor output (gray levels)



Sensor output (color mosaic)



Demosaiced (Adams Hamilton 1996)

Color matrix

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} m_{RR} & m_{GR} & 1 - m_{RR} - m_{GR} \\ m_{RG} & m_{GG} & 1 - m_{RG} - m_{GG} \\ m_{RB} & m_{GB} & 1 - m_{RB} - m_{GB} \end{pmatrix} \begin{pmatrix} \lambda_R & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \lambda_B \end{pmatrix} \gamma \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Color management

White balance

Exposure

9 DoF = 6 DoF + 2 DoF + 1 DoF

Exposure

× 2

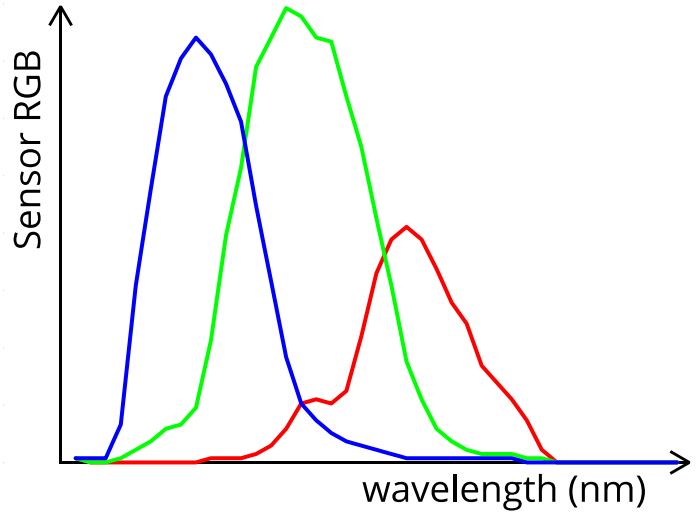
+ 1 EV

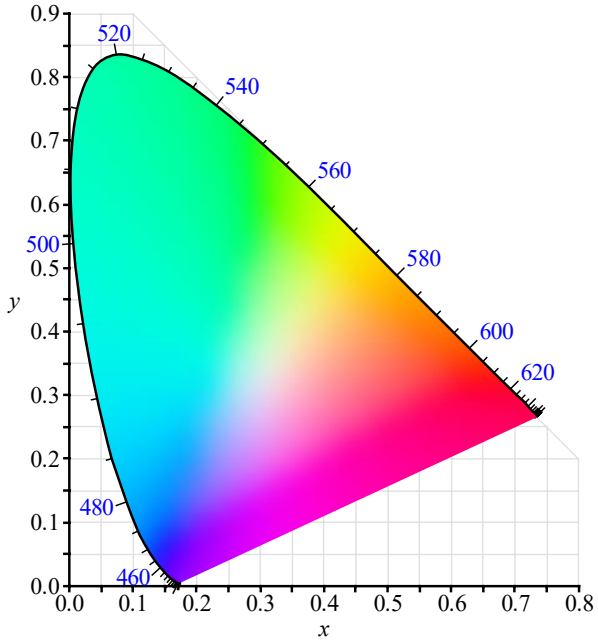
× 2

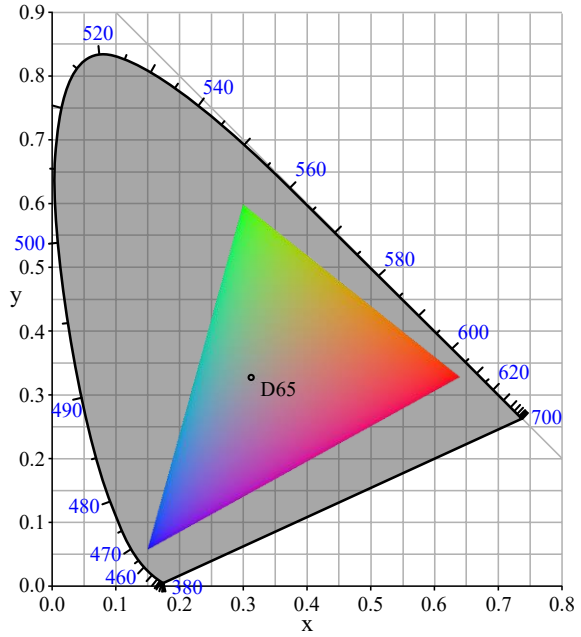
+ 1 EV

White balance

Color management







Source
RGB

Profile connection
space

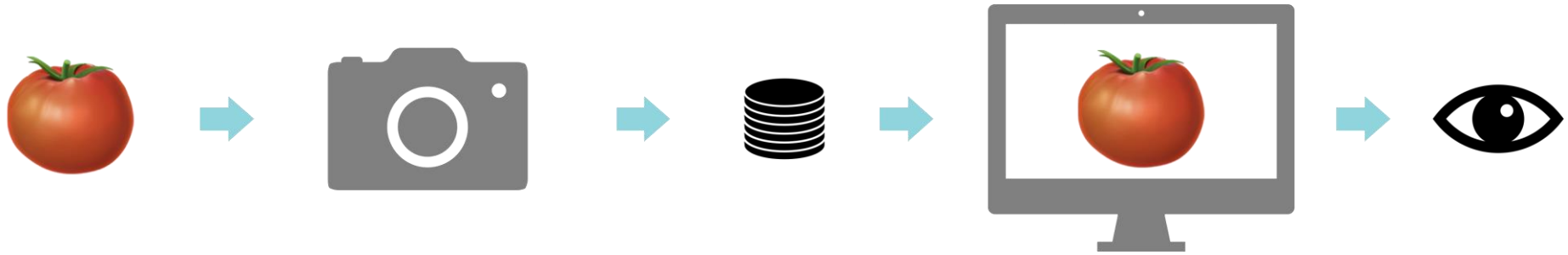
Device independent

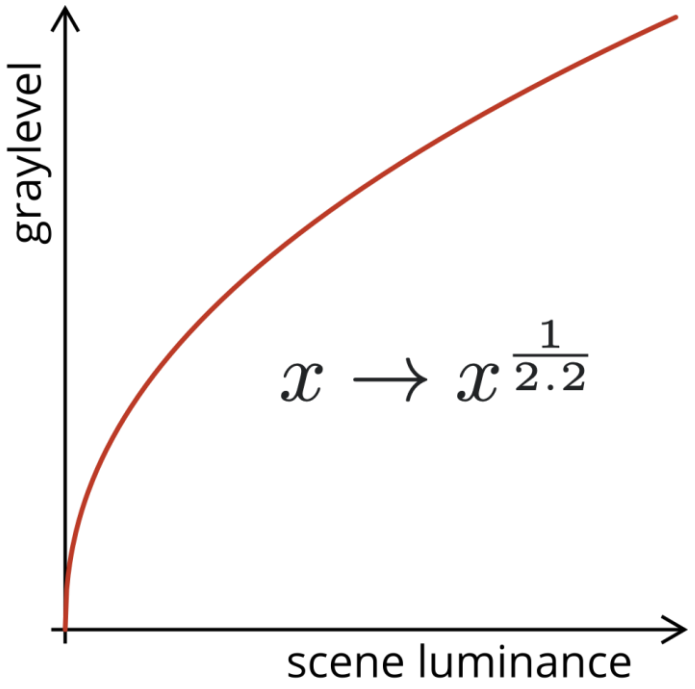
Target
RGB

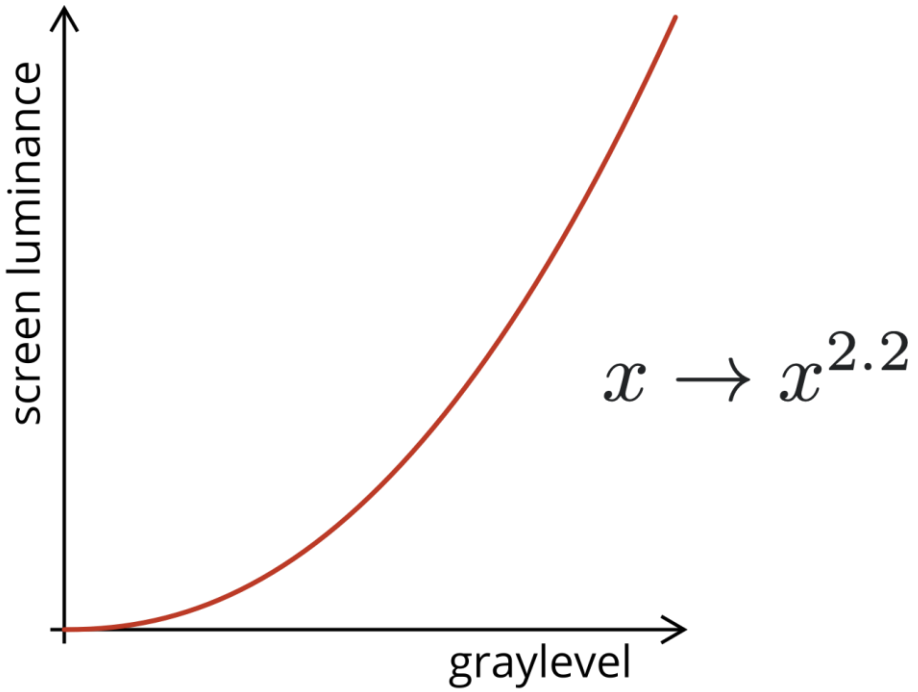
DXOMARK

Color management

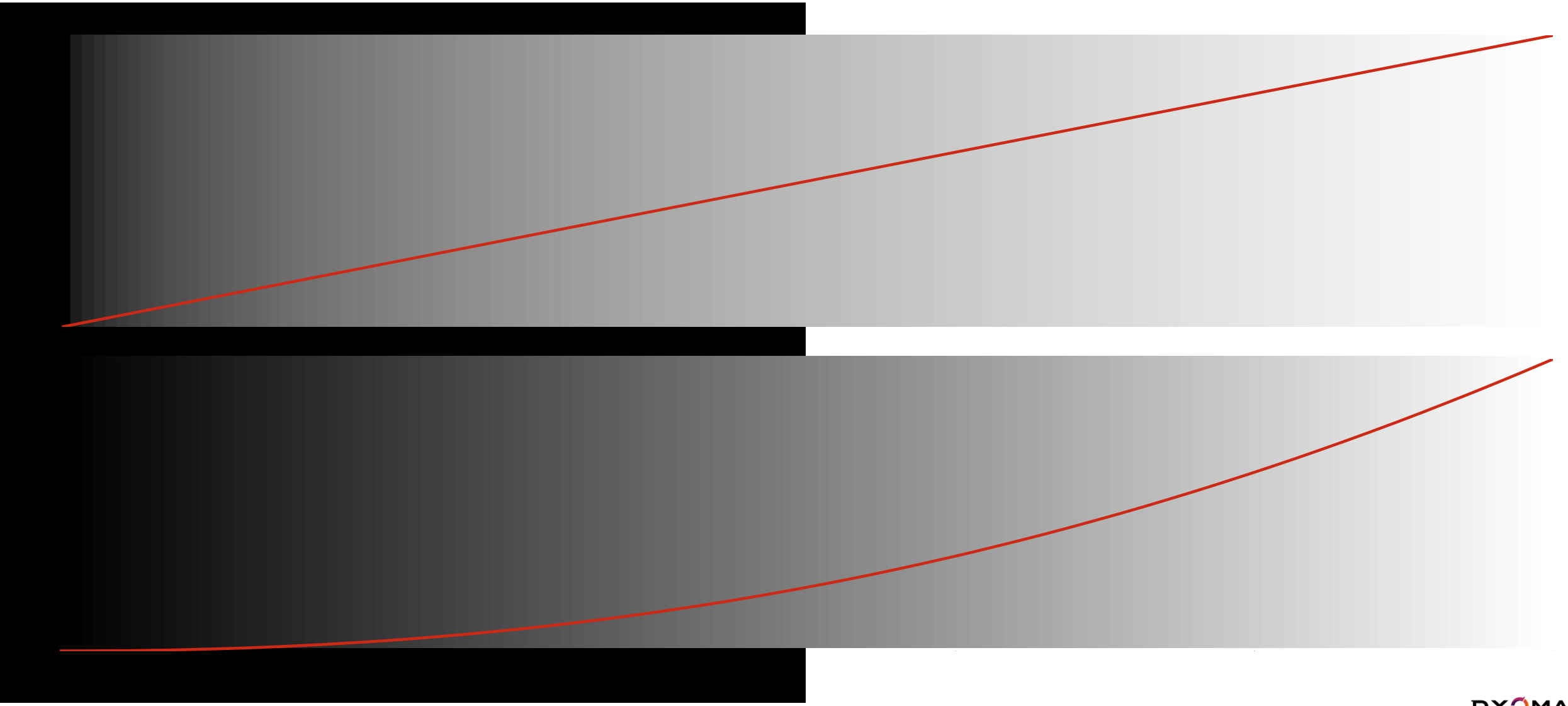
Gamma correction







Gamma correction



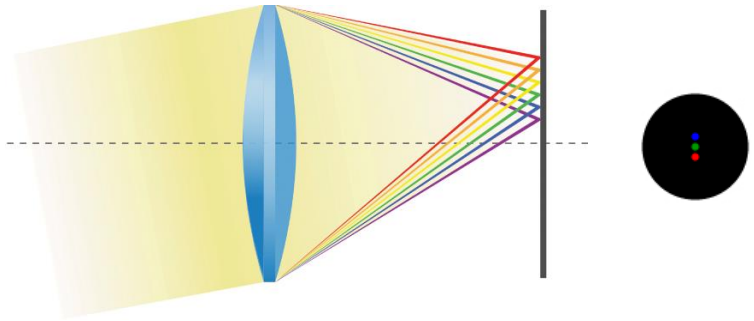
Lens corrections – Distortions

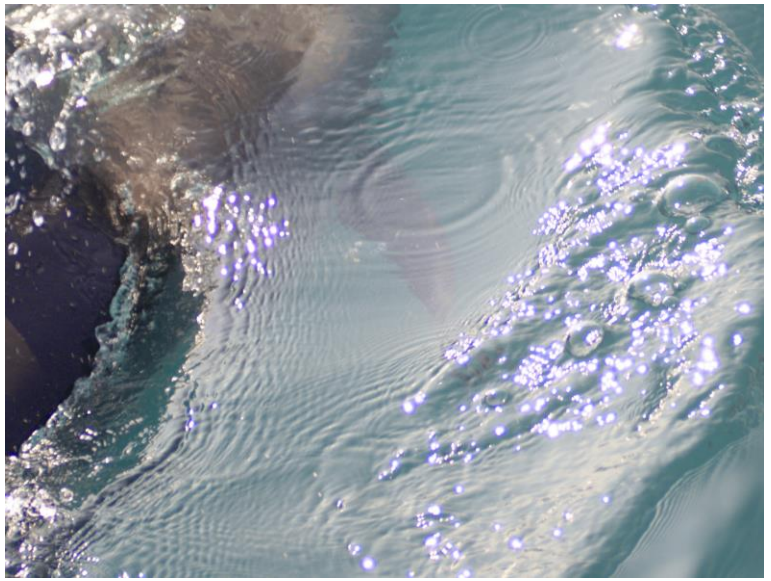
Photo: Hugo Uyttersprot

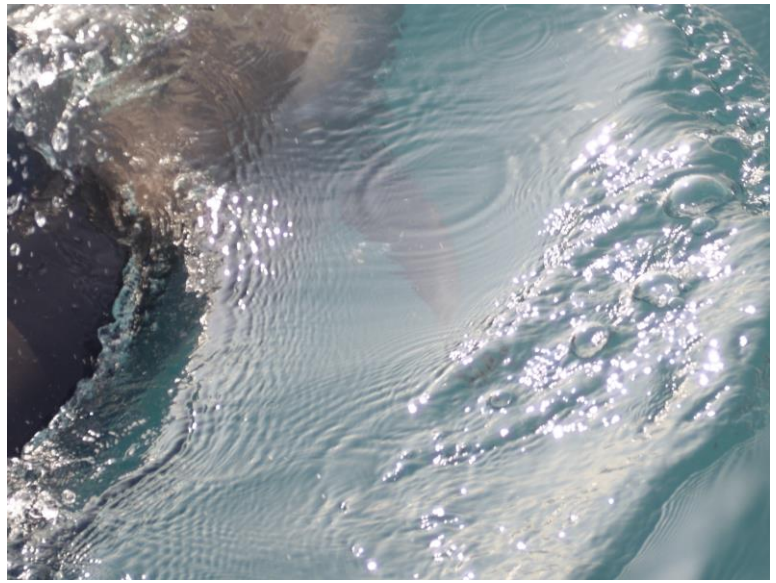
Lens corrections – Vignetting aka Lens shading

Lens corrections – Chromatic aberrations

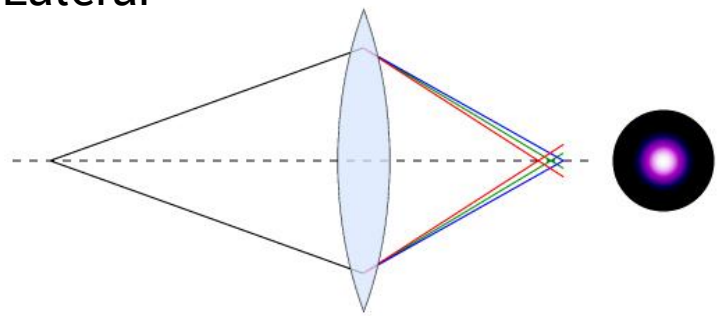
Longitudinal







Lateral



Denoising

Color saturation enhancement

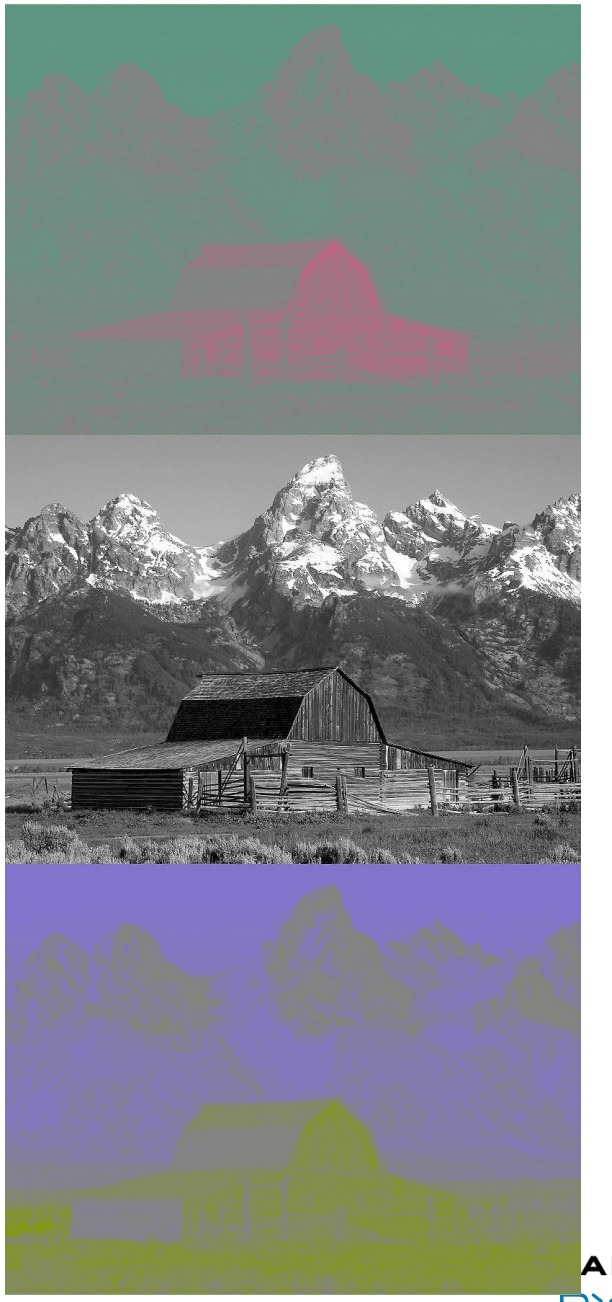
Contrast enhancement (global)

Contrast enhancement (local)

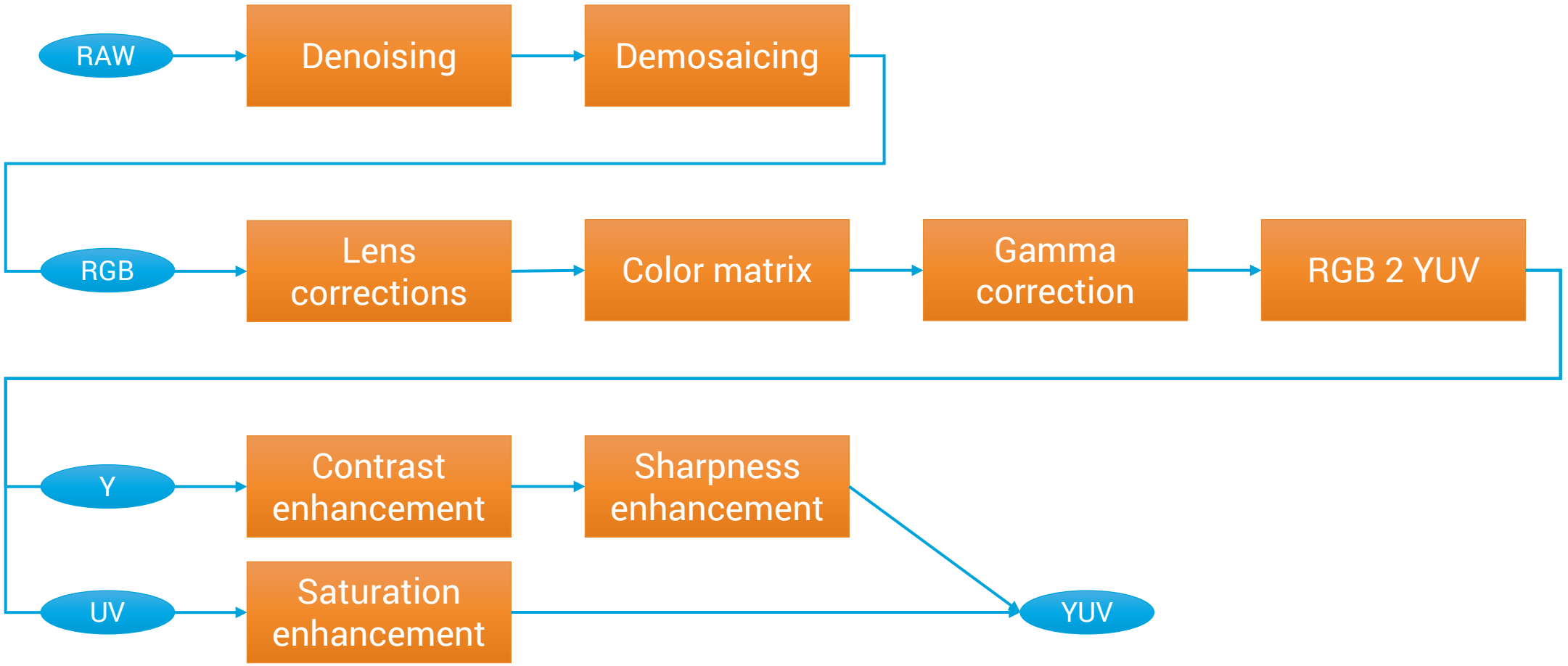
Sharpness enhancement

Chroma – Luma

Source: https://en.wikipedia.org/wiki/YCbCr



Pipeline example



Smartphone’s Camera ingredients

- Camera module(s)
  (and other sensors)

- **Chipset (ISP)**
  - introduction
  - Camera controls
  - The “image pipe”
  - **Architecture**

ISP – a typical architecture (simplified)

ISP block

HW signal processing block, 1 pixel in, 1 pixel out. Local access only. Same story for all pixel.

CSID

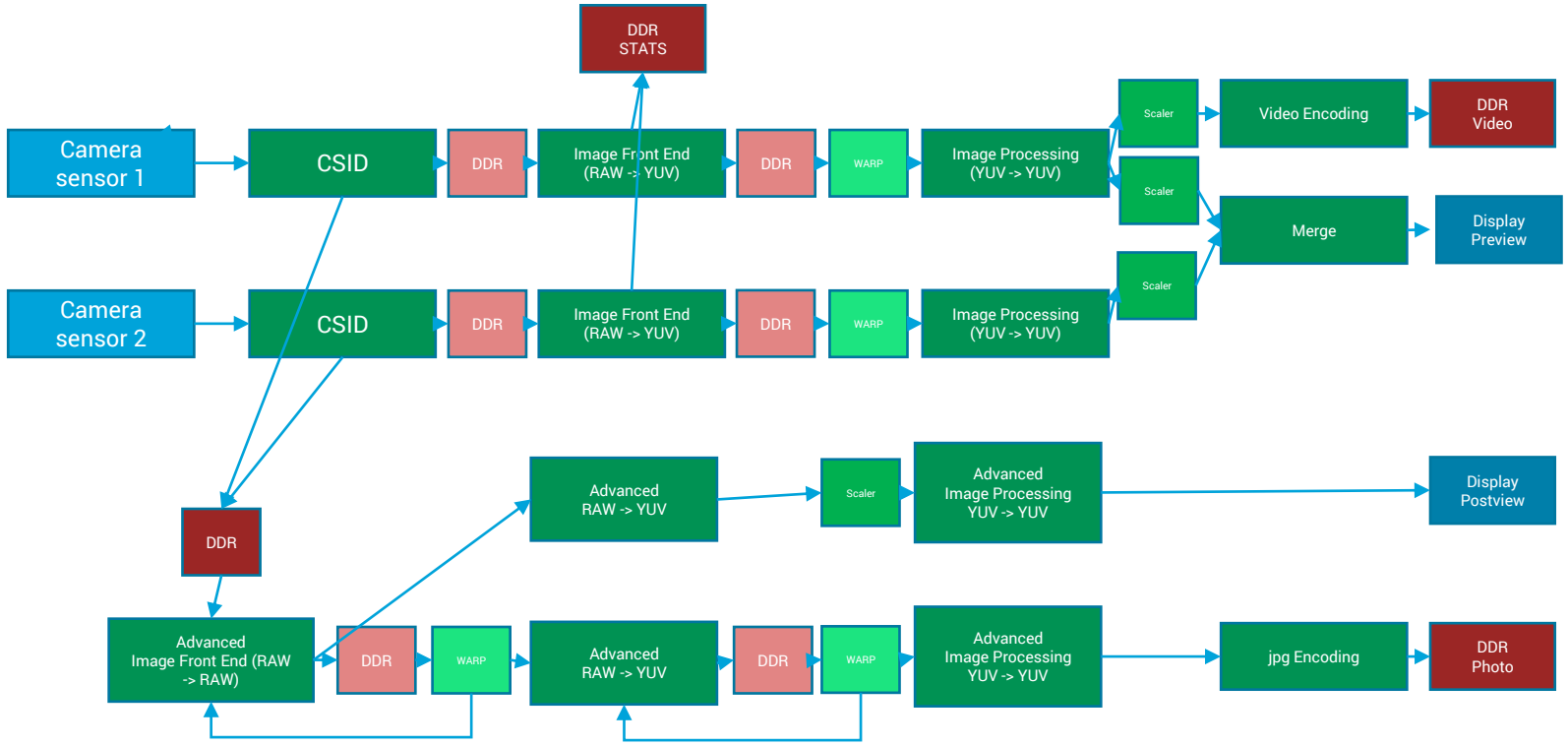
Camera Serial Interface decoder

DDR

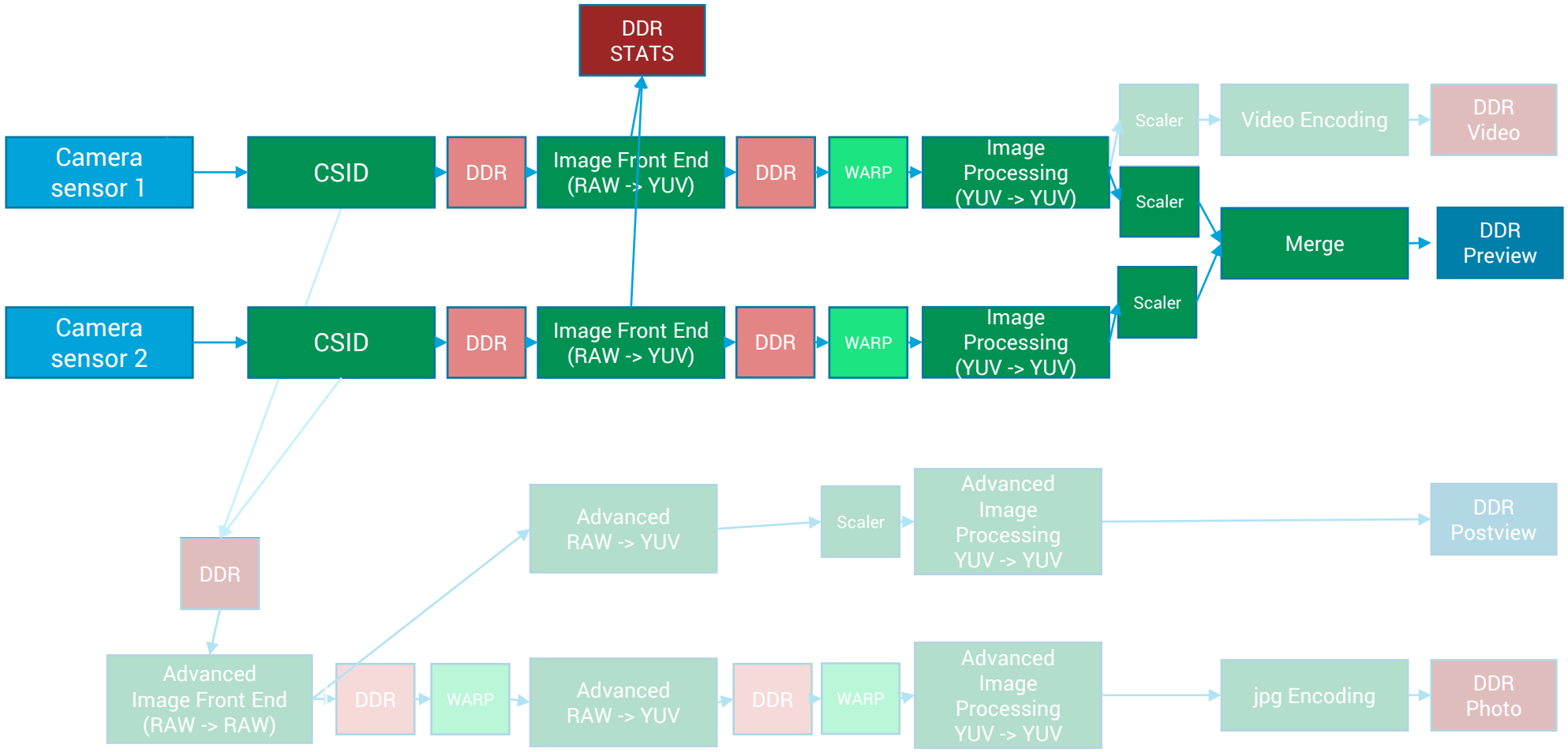
(Optional) back to RAM. Allow buffering and/or additional CPU/GPU processing. But… costly.

Warp/scaler

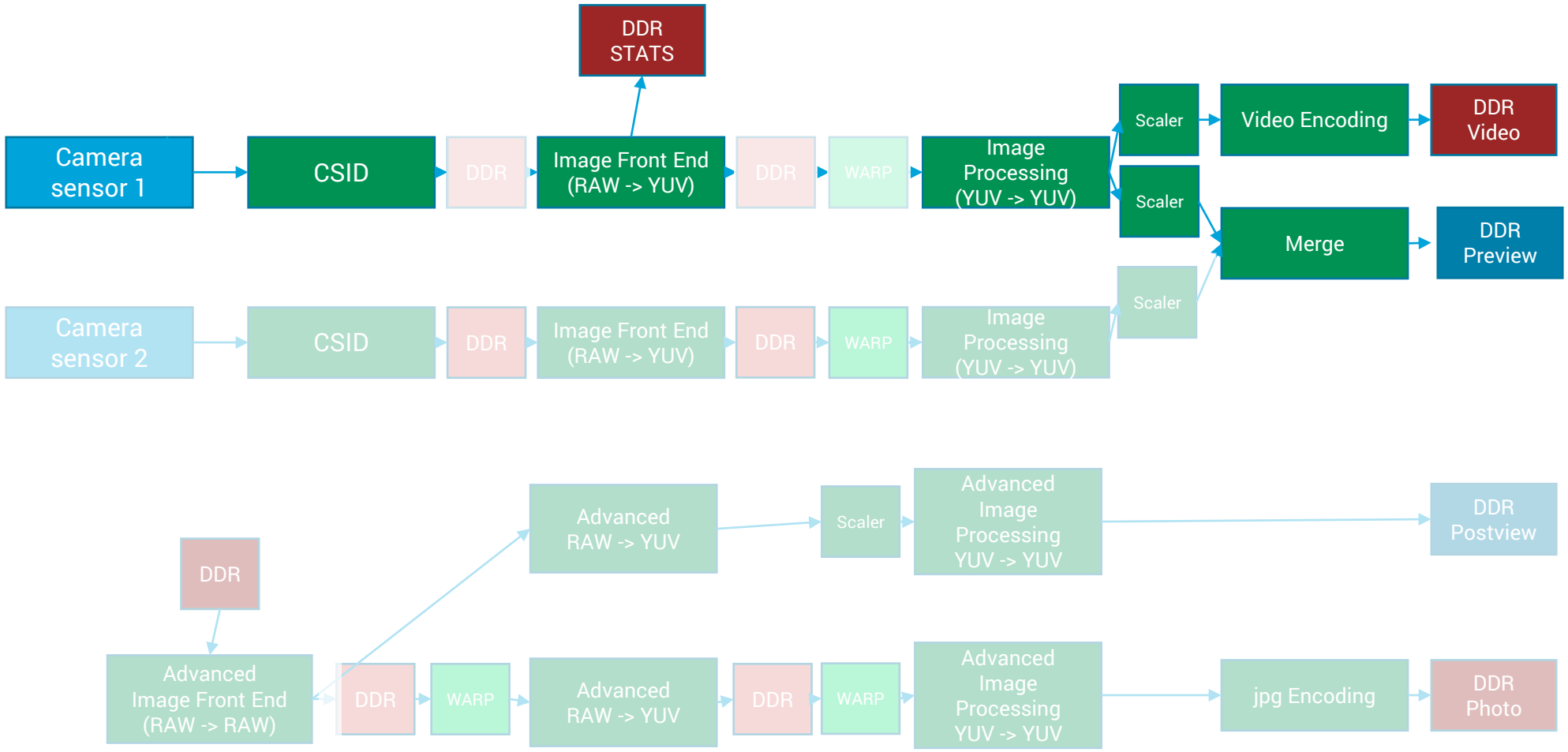
Things that can not be performed by an ISP block…



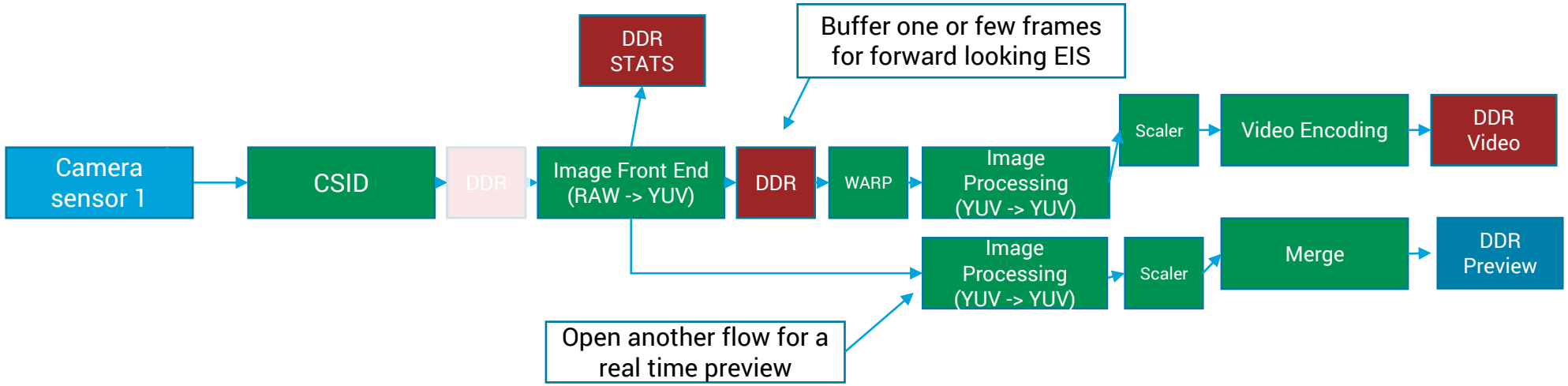
ISP – During Preview



ISP – During video recording, without EIS



ISP – During video recording, with forward looking EIS

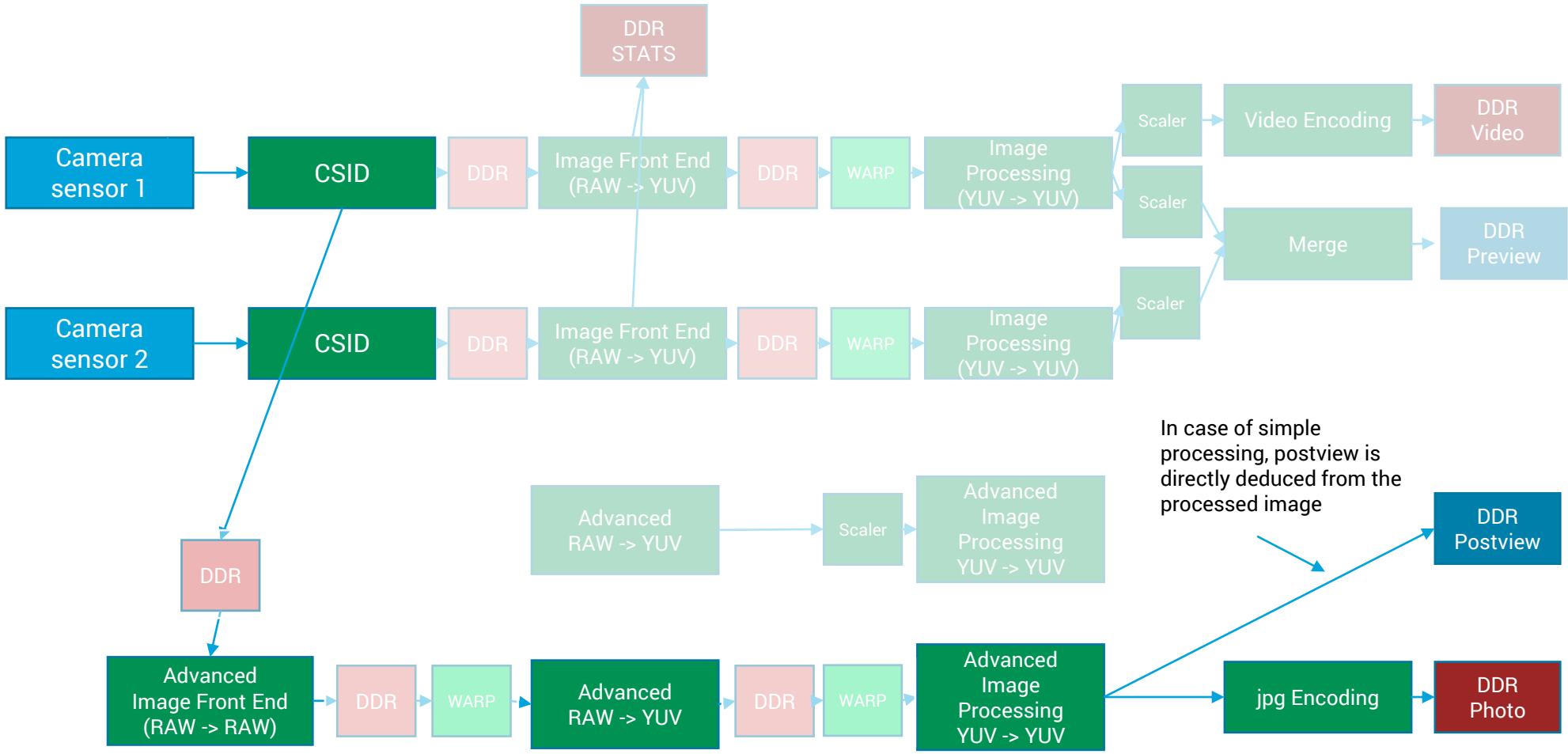


"**Forward looking EIS**" = a better video stabilization is obtained if we know the future motion of the camera.

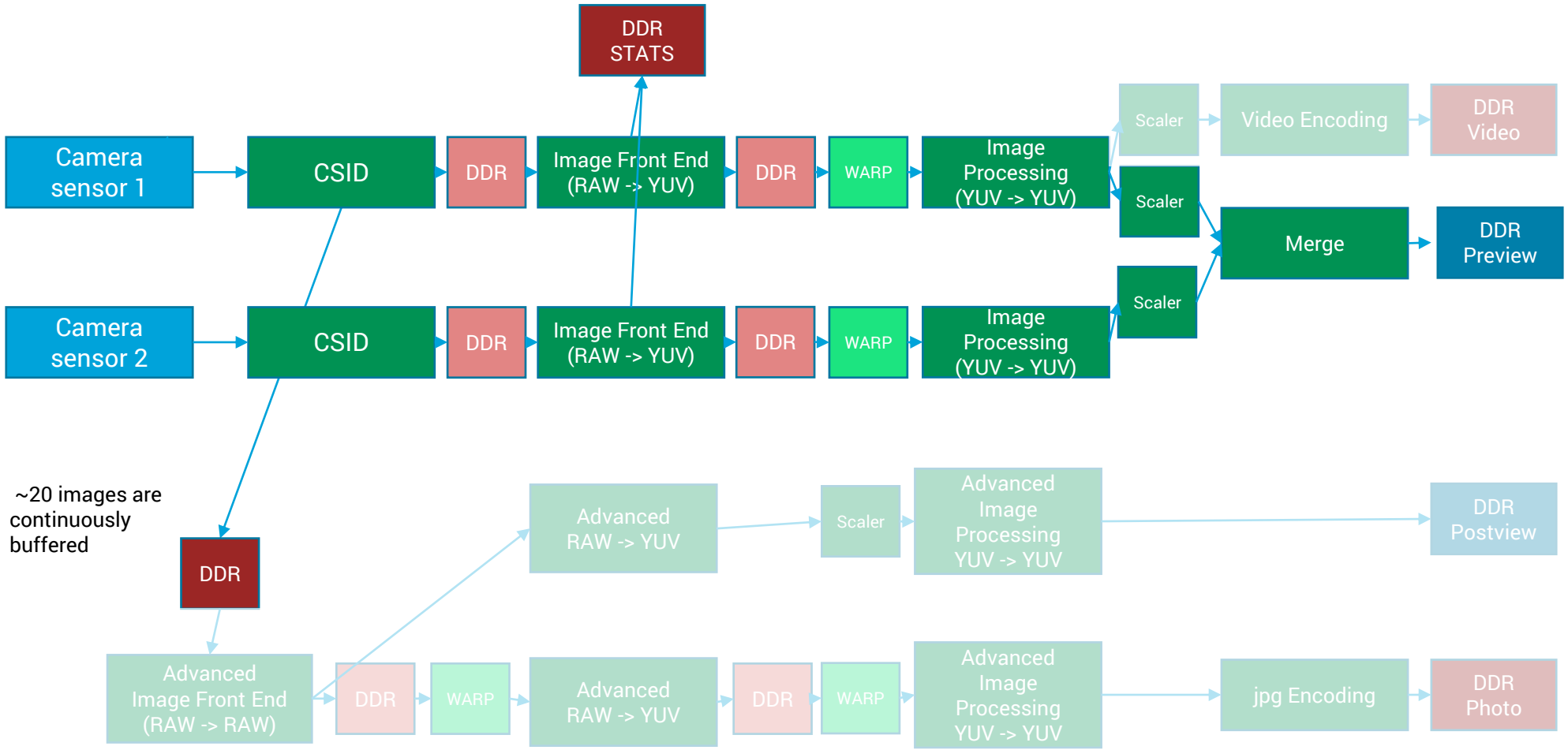
Idea = **buffer** several **frames** in DDR, delay accordingly the processing/encoding.

In order to keep a real time preview, open another processing pipe, quickly processing the just captured frame just for preview.

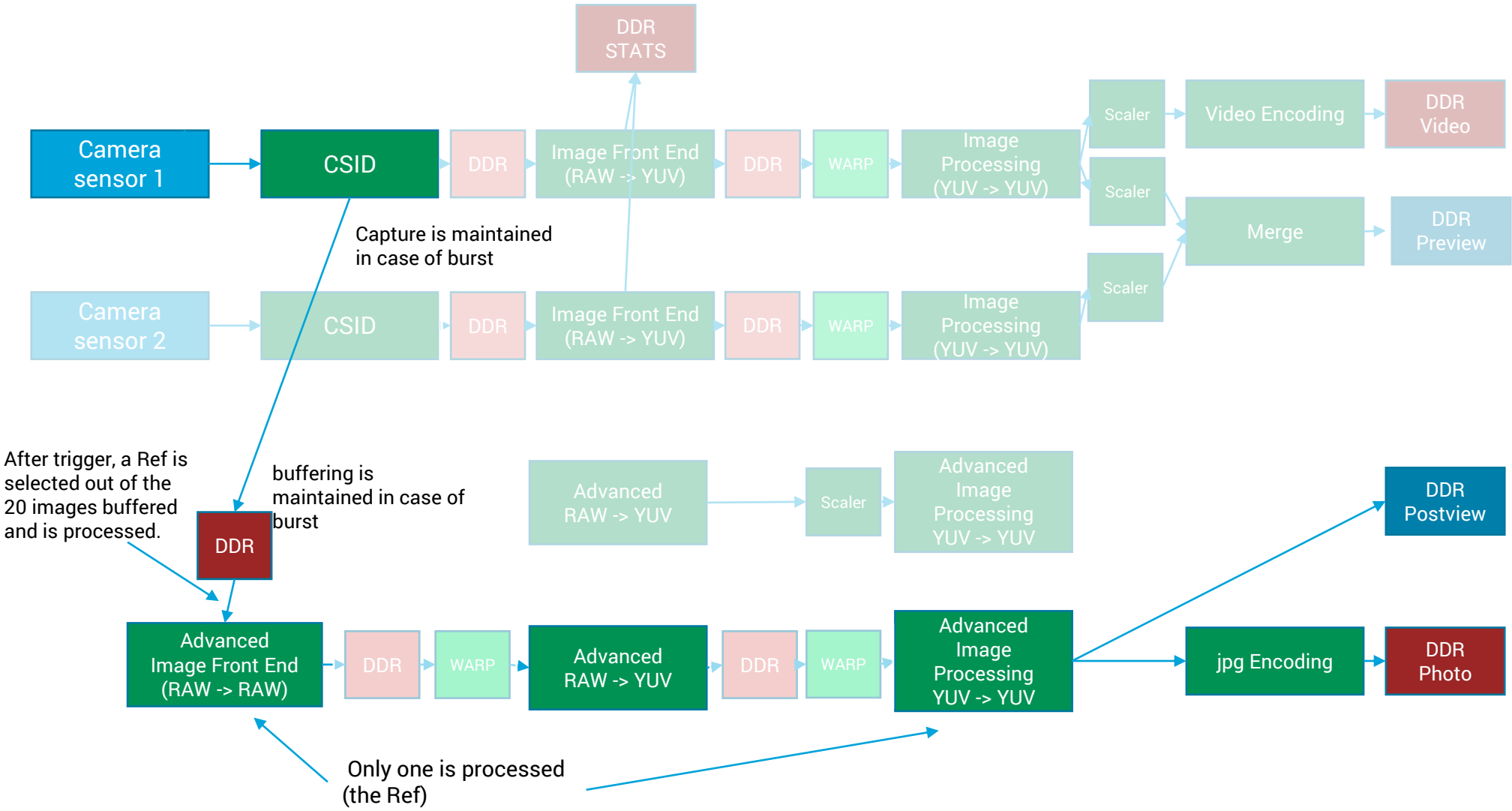
ISP – Case 1: photo capture. Single image captured after trigger



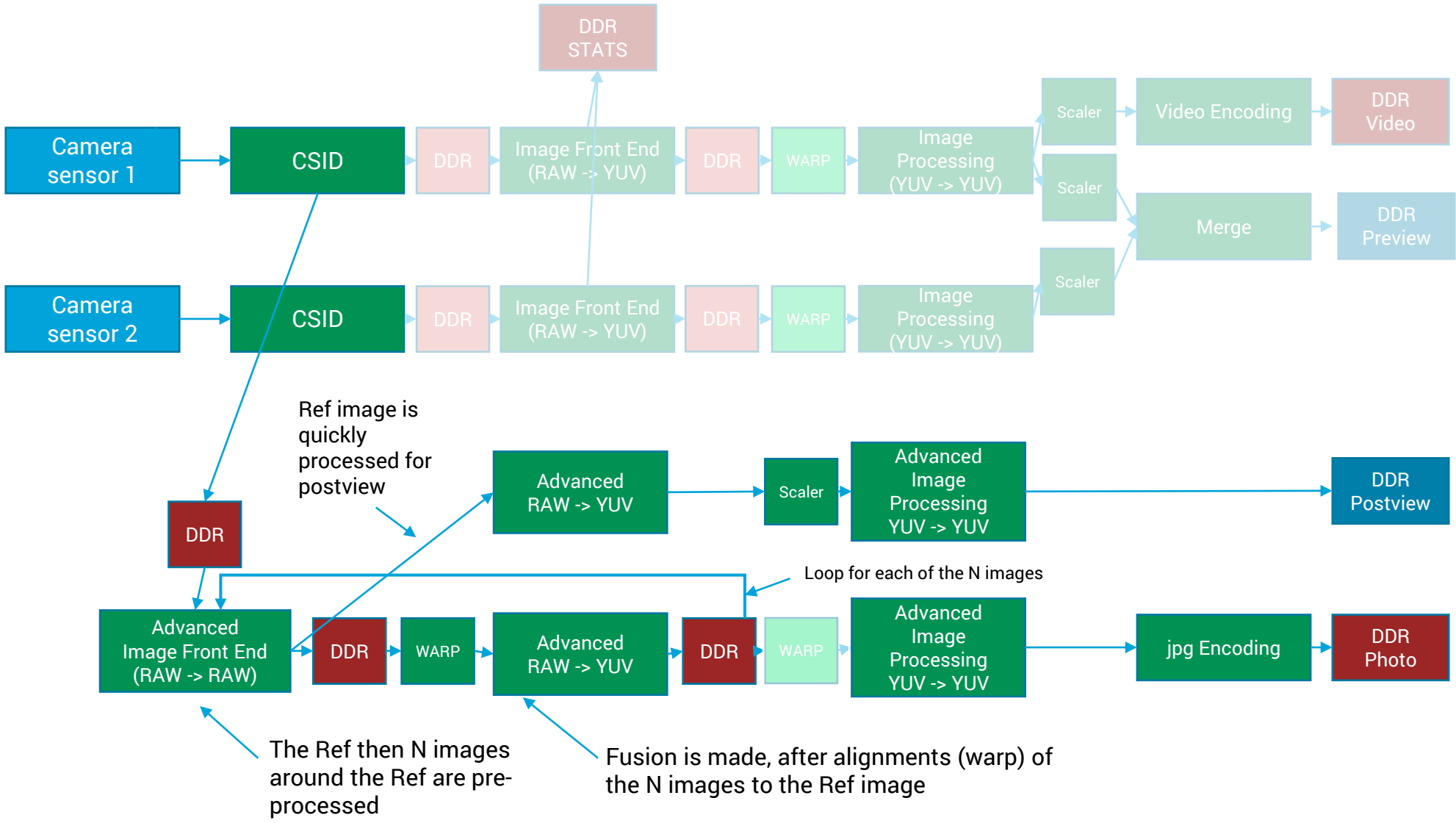
ISP – Case 2 : Zero shutter lag. “before trigger”



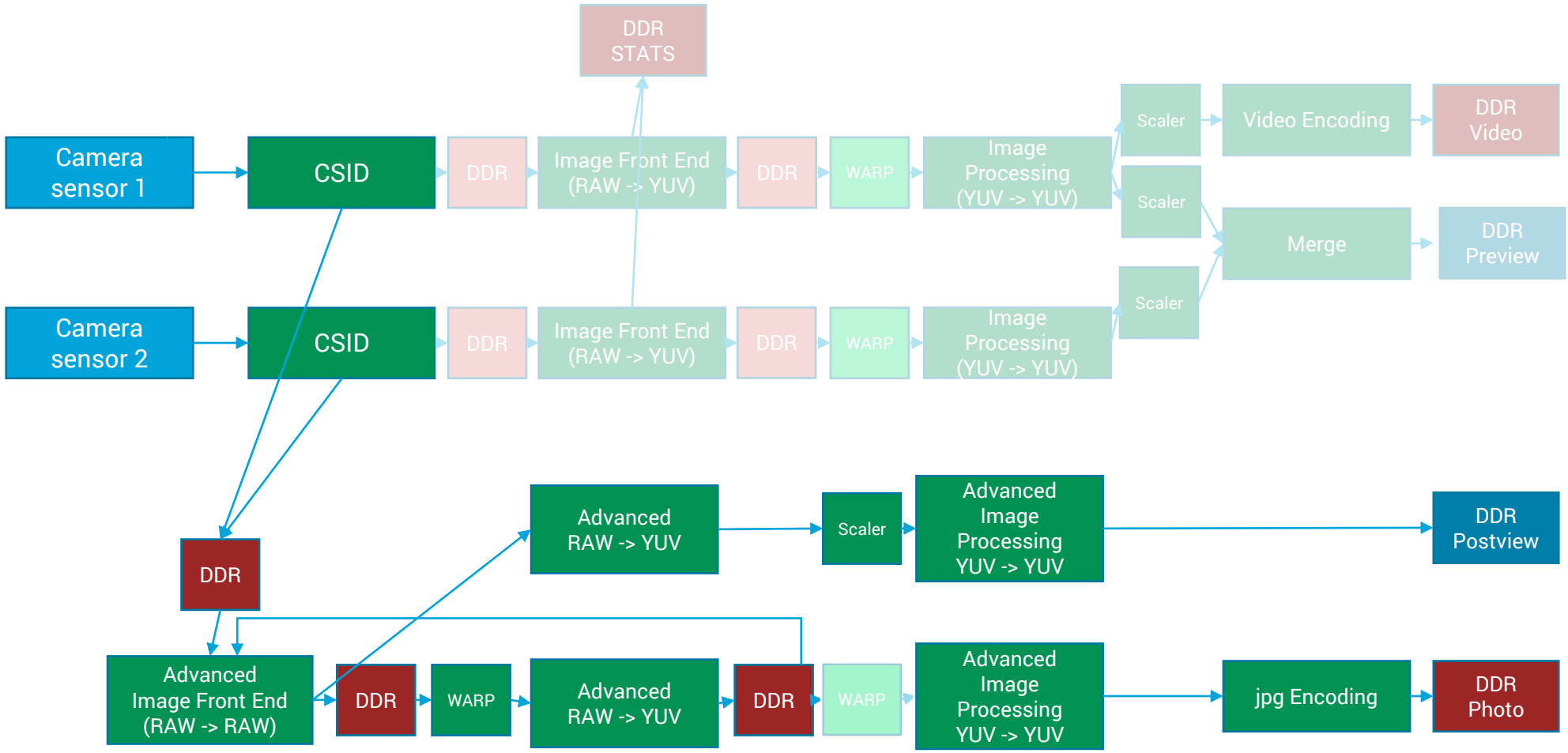
ISP – case 2 : Zero shutter lag – “after trigger” (single image, simple processing)



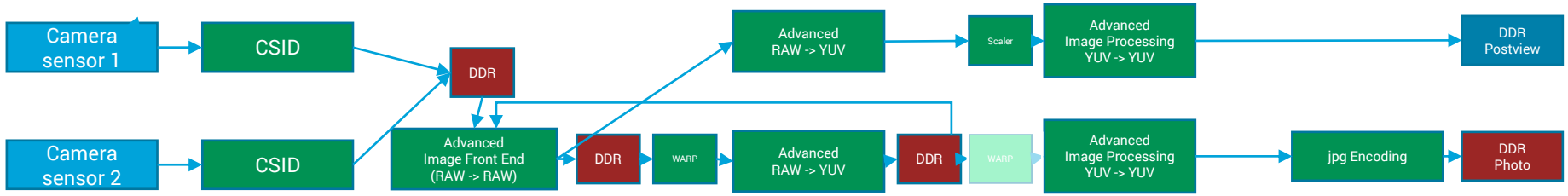
ISP – case 3 : Zero shutter lag, multi images



ISP – Case 4, ZSL, Multi images, multi cameras.



ISP – HW or SW processing ?



HW : 30 T Ops/s, low power consumption, but… fixed processing.

SW : about 2.7T Ops/s.
Not enough to handle 4K60 video.
But… enough to handle photo processing.

SW in background processing, can take time

Real time appearance made thanks to HW generated Postview.

Artificial Intelligence

Qualcomm® Adreno™ GPU

Qualcomm® Kryo™ CPU

Qualcomm® Hexagon™ Processor

- Fused AI Accelerator Architecture
- Hexagon Tensor Accelerator
- Hexagon Vector eXtensions
- Hexagon Scalar Accelerator
- Hexagon Direct Link
- Support for mix precision (INT8+INT16)
- Support for all precisions (INT4, INT8, INT16, FP16)
- Micro Tile Inferencing

Qualcomm® Sensing Hub

- Dual AI Processors for audio and sensors
- Always-Sensing camera

5G Modem-RF System

Snapdragon® X70 5G Modem-RF System

- 5G mmWave and sub-6 GHz, standalone (SA) and non-standalone (NSA) modes, standalone mmWave and mmWave-sub6 dual connectivity, FDD, TDD
- mmWave: 8 carriers, 2x2 MIMO
- Sub-6 GHz: 4x4 MIMO
- Qualcomm® 5G AI Suite
- Qualcomm® AI-Enhanced Signal Boost
- Qualcomm® 5G PowerSave Gen 3

Camera

Qualcomm Spectra™ Image Signal Processor

- Cognitive ISP, Triple 18-bit ISPs
- Up to 36 MP triple camera @ 30 FPS with Zero Shutter Lag
- Up to 64+36 MP dual camera @ 30 FPS with Zero Shutter Lag
- Up to 108 MP single camera @ 30 FPS with Zero Shutter Lag
- Up to 200 Megapixel Photo Capture

AI-based face detection, auto-focus, and auto-exposure

Rec. 2020 color gamut photo and video capture

Up to 10-bit color depth photo and video capture

8K HDR Video Capture + 64 MP Photo Capture

10-bit HEIF: HEIC photo capture, HEVC video capture

Video Capture HDR Formats: HDR10+, HDR10, HLG, Dolby Vision

8K HDR Video Capture @ 30 FPS

4K Video Capture @ 120 FPS

Slow-mo video capture at 720p @ 960 FPS

8K Video Playback @ 60 FPS

Engine for Visual Analytics 3.0

CPU

Kryo CPU

- 64-bit Architecture
- 1 Prime core, up to 3.2 GHz[2]
  - Arm Cortex-X3 technology
- 4 Performance cores, up to 2.8 GHz
- 3 Efficiency cores, up to 2.0 GHz

Visual Subsystem

Adreno GPU

- Real-time Hardware Accelerated Ray Tracing
- Snapdragon Game Post Processing Accelerator
- HDR gaming (10-bit color depth, Rec. 2020 color gamut)
- Snapdragon Shadow Denoiser
- API Support: OpenGL® ES 3.2, OpenCL™ 2.0 FP, Vulkan® 1.3
- Hardware-accelerated H.265 and VP9 decoder
- HDR Playback Codec support for HDR10+, HDR10, HLG, and Dolby Vision

Security

Platform Security Foundations, Trusted Execution

Environment & Services, Secure Processing Unit (SPU)

Trust Management Engine

Qualcomm® wireless edge services (WES) and

DXOMARK
DXO

Conclusion : Smartphone’s Camera ingredients - Conclusion

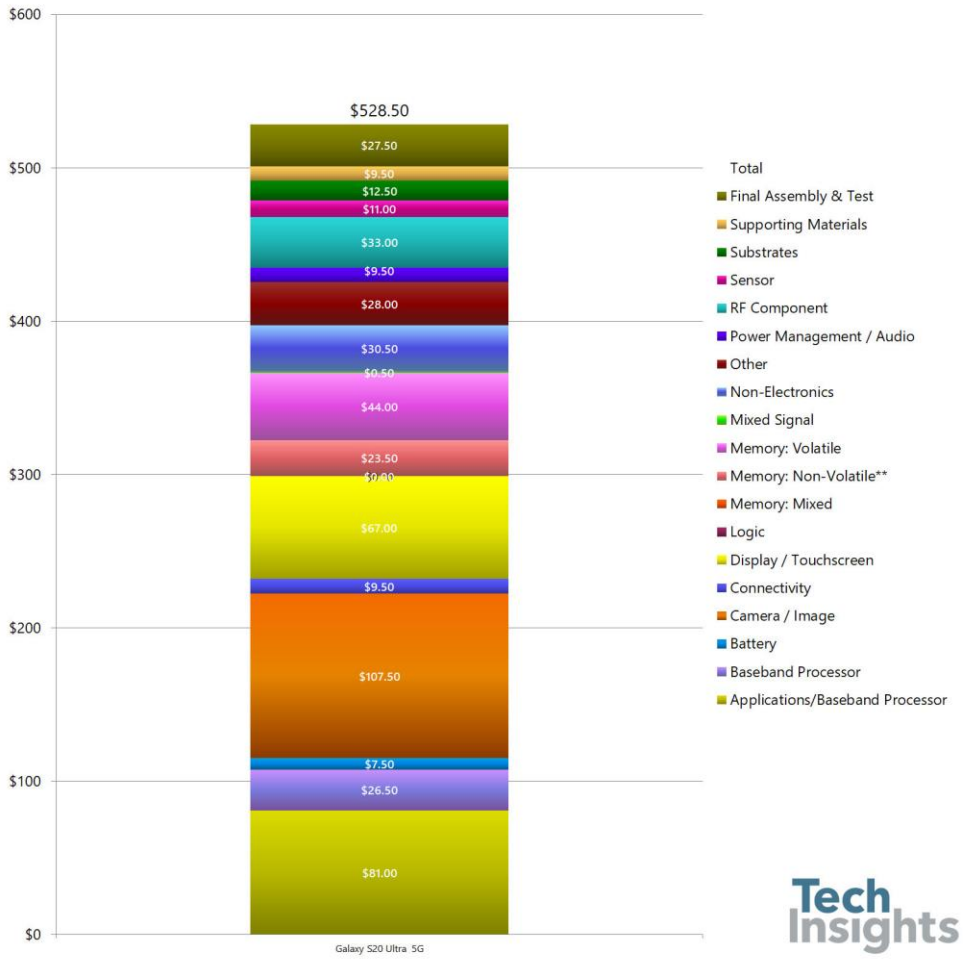
- **Camera module(s)**
  (and other sensors)
- **Chipset (ISP)**

Conclusion : Smartphone camera = not so simple

Camera = a significant part of the BOM

- Chipset: 15%
- Screen: 12%
- Camera: 22%
- Memory : 13%
- Comm: 9%
- Substrates+ID : 12%
- Assembly and Tests: 5%
- Battery: 2%
- Audio: 1%
- Others stuff : 10-%

Also a significant part of the R&D costs…



THANK YOU !

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